Offshore Oligo-Miocene volcanic fields within the Corsica-Liguria Basin: Magmatic diversity and slab evolution in the western Mediterranean Sea

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Abstract

The European and Corsica-Sardinia margins of the Ligurian Sea (western Mediterranean) have been affected by a geochemically diverse igneous activity, offshore and onshore, since the Eocene. This magmatism occurred in a global subduction-related framework. On the European side, the oldest Tertiary magmatism dated at ca. 35 Ma was mainly calc-alkaline. It included the emplacement of plutonic bodies of adakitic affinity, such as the quartz microdiorite laccolith locally referred to as "esterellite". Younger magmatic events on-land within the whole Ligurian domain were mostly medium-K or K-rich calc-alkaline. Miocene volcanic activity was important in Sardinia, where andesites and ignimbrites were erupted during several magmatic cycles. In Corsica, it was minor although it emplaced lamprophyres near Sisco at 15 Ma.

Dredging and diving cruises conducted in the Ligurian Sea during the last thirty years allowed us to collect a number of submarine samples. We discuss here their geochemistry (major and trace elements) and their whole-rock K-Ar ages and mineral ^{40}Ar-^{39}Ar plateau ages. Around 15 Ma, minor amounts of adakitic lavas were emplaced off southwestern Corsica, in the deepest part of the Liguria-Corsica Basin. They rested over the thinnest southwestern Corsica Hercynian continental crust. Closer to the coast, contemporaneous calc-alkaline rocks erupted

on a less thinned crust. The adakitic events could be indicative of either the final stages of active subduction, or alternatively of a slab tearing linked to the southeastern retreat and steepening of the slab. The latter event could be connected with the end of the Corsica-Sardinia block drifting and its correlative eastern collision.

Younger volcanic effusions, dated at 14-6 Ma, occurred mostly northwest and north of Corsica. K-rich calc-alkaline basalts, shoshonites and K-rich trachytes were emplaced during this period, and alkali basalts erupted as early as 12 Ma in Sardinia. In the Toulon area, alkali basalts dated at 7-6 Ma represent the last onshore activity just before the Messinian crisis, and the Pliocene alkali basaltic outpouring in Sardinia. We propose to link these latter volcanic events to the development of a slab window in a post-collisional tectonic framework.

This work is dedicated to the memory of our colleague Henriette Lapierre, Professor at Grenoble University, who died in January 2006. She was an important contributor to our initial project.

Key-Words: Mediterranean, Ligurian margins and Basin, Offshore Corsica, Miocene (K-Ar and ^{40}Ar-^{39}Ar ages), Normal and K-rich calc-alkaline lavas, Adakites, Shoshonites, Alkali basalts, Slab breakoff, Slab tearing, Slab window, Subduction.

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1. Introduction

The Mediterranean domain represents a wide, geodynamically active area where the Cenozoic convergence between the African and Eurasian plates resulted in a complex spatial and temporal tectonic pattern. Between Alps-Provence and Corsica, a highly thinned continental crust on the deep part of the margins underlies the Ligurian Sea, while an oceanic-type crust is present in its narrow central part. Corsica and Sardinia islands are underlain by a "typically" Variscan bowl-shaped continental crust (Galson and Mueller, 1986).

During the Neogene, the western Mediterranean domain and its margins evolved through a complex succession of NW-directed subductions, back-arc openings and collisions, involving

slab tearings and detachments (Réhault et al., 1984; von Blanckenburg and Davies, 1995; Gueguen et al., 1998; Carminati et al., 1998a, 1998b; Faccenna et al., 2004; Lucente et al., 2006; Carminati et al., 2010; Lustrino et al., 2011).

The magmatic activity linked to these complex geodynamic patterns led to the emplacement, both onshore and offshore, of geochemically diverse volcanic and plutonic associations. These include MORB-type and back-arc oceanic basalts (Beccaluva et al., 1990), from calc-alkaline to ultrapotassic lavas (Peccerillo, 2005), plutonic and volcanic rocks of crustal anatectic origin (Zeck et al., 1998) and alkali basalt series (Oyarzun et al., 1997; Lustrino and Wilson, 2007). These complex rock associations occur throughout the whole Mediterranean domain, e.g. in the Betic Cordilleras (Zeck et al., 1996; Benito et al., 1999), the Maghreb alpine chain (Maury et al., 2000), the Apennines-Calabrian-Sicilian domain and the Eolian arc and Tuscany (Hawkesworth and Vollmer, 1979; Savelli, 1988; Lustrino et al., 2011).

Within the Liguro-Provençal Sea and its margins as well as on the Sardinia-Corsica block, a Neogene magmatic evolution from medium-K calc-alkaline towards K-rich calk-alkaline lavas was followed by the emplacement of alkali basaltic lavas in the Toulon area (France) and in Sardinia (Coulon, 1977; Montigny et al., 1981; Dostal et al., 1982; Aguilar et al., 1996; Morra et al., 1997; Gattacceca, 2001; Gattacceca et al., 2007; Lustrino et al., 2007a, b). In Corsica, the only evidences are the Sisco lamprophyre at Cap Corse and the ignimbritic tuffs of Balistra (Bellon, 1976) and the Tre Paduli, Francolu, and Maore (Ottaviani-Spella et al., 1996, 2001; Ferrandini et al., 2003). The geochronology and geochemistry of this onshore magmatic activity, which has been related to the drifting of the Sardinia-Corsica block, are relatively well documented (Bellon and Brousse, 1977; Wilson and Bianchini, 1999: Savelli, 1979, 1988, 2002; Oudet et al,. 2010, Lustrino et al., 2011).

In comparison with onshore igneous rocks, the literature data on the offshore volcanics from the Ligurian Sea are nearly completely missing. The present paper is based on the study of the dredging and diving cruises carried out by French scientific institutions that sampled a large number of volcanic rocks during the three last decades in the Corsica-Liguria Basin. Our new data highlight the tectono-magmatic processes ,which controlled the Tertiary evolution of the northwestern Mediterranean domain.

2. Northwestern Mediterranean magmatic events

2.1.Onland magmatism in SE France, Corsica and Sardinia

Tertiary magmatic rocks are present mainly in the emerged part of the northern Ligurian

margin. They are well-known since the XIXth century, especially the “porphyre bleu de l’Estérel” or “estérellite” (Michel-Lévy, 1898), a quartz-bearing microdiorite forming a thick laccolithic complex near Le Drammont. Basaltic to andesitic pyroclastic deposits cropping out around Villeneuve-Loubet were described by Brousse and Lefèvre (1990). Finally, andesitic and dacitic pebbles occur in volcanogenic breccias interbedded within the Eocene sedimentary rocks in the Saint-Antonin syncline, located to the north of Nice (Féraud et al., 1995; Boyet et al., 2001).

The first published K-Ar age at 26.2 ± 1.2 Ma (Bellon and Brousse, 1971) concerned the andesites exposed between Biot and Grasse. Complementary ages carried on lavas collected at Tourettes sur Loup, Juan-les-Pins and La Vanade, are bracketed between 32.5 and 30.8 Ma (Bellon, 1981). More recently, two pyroclastic levels sampled during the Monaco railway tunnel engineering works were dated at respectively 27 ± 0.8 and 18.7 ± 0.8 Ma (Ivaldi et al., 2003). ^{40}Ar-^{39}Ar ages for Le Drammont microdiorites and for the Saint-Antonin andesites range from 33 to 31 Ma (Féraud et al., 1995). Similar plateau ages (31-30 Ma) have been measured on Alpine plutons such as Traversella and Biella (Ruffet, unpublished data) and nearby bodies of similar ages (32-29 Ma; Buergi and Kloetzli, 1990; Romer et al., 1996). Andesitic to dacitic pebbles from a volcanoclastic unit interbedded within an Early Oligocene (Priabonian-Rupelian) marine formation at the Baratus pass, in the vicinity of St Auban, have been dated at 29.6 ± 0.5 and 29.0 ± 0.5 Ma (Montenat et al., 1999).

Northwest of Aix en Provence, at Beaulieu, two Miocene volcanic events emplaced a calc-alkaline lava flow and an alkali basaltic flow, respectively (Gueirard, 1964), which have been considered later as transitional to alkaline by Dautria and Liotard (1990). The Formation de Beaulieu, which includes coastal deposits overlain by lacustrine limestones, is subcontemporaneous of this volcanic complex. ^{40}Ar-^{39}Ar dating of a basaltic sample taken in the quarry site, previously studied by Baubron et al. (1975), yielded a plateau age of 17.5 ± 0.3 Ma, which can be correlated with N6 + N7 biozones dated in the neighbouring marine sediments and the paleomagnetic chrone C5Dn (Aguilar et al., 2003). It is consistent with the previous K-Ar age of ca. 18.2 ± 0.5 Ma (Baubron et al., 1975). North of Toulon, alkali basaltic flows dated at 6.97 ± 0.24 and 6.30 ± 0.22 Ma (Bellon, unpublished data) represent the last volcanic event known in Provence (Coulon, 1967; Gouvernet et al., 1997).

The important Neogene magmatic activity documented in Sardinia may be divided in two main periods. The first one occurred between 32 and 15 Ma with a peak between 22 and 18 Ma, and the second one emplaced alkali basalts between 12 and 0.1 Ma (Lustrino et al., 2007). In Northeast Corsica, lamproitic dykes intruding the “Schistes lustrés” unit yielded a whole rock K-Ar age of 13.75 Ma (Bellon, 1976, age corrected according to constants in Steiger and Jäger,

1978) and a Rb-Sr age of 15 Ma (Féraud et al., 1977). Their emplacement is related to that of K-rich and shoshonitic lavas in Sardinia.

2. 2. Offshore Corsica-Liguria Basin volcanism

Offshore volcanism appears relatively scattered within the Corsica-Liguria basin, which comprises the Ligurian Sea and its submarine margins. However, two main volcanic fields are distinguished in Fig. 1. The first one, the southwestern Corsica volcanic field, is located in the prolongation of the central Sardinia rift, while the second one, the northwestern Corsica volcanic field, is located south of Genoa Gulf and along the Central Ligurian Sea. This latter field underlines the N10°-20° trending foot of the Corsica continental margin and Liguria Central Basin.

A large set of pre-existing data and studies have been considered in our study. It includes previous geological samplings, bathymetric and geophysical data, large transverse magnetic anomalies southwest of Corsica (Bayer, 1974), dredged samples in the Ligurian basin (Réhault et al., 1974), identification of reflectors of the Ligurian margins (Bellaiche et al., 1974), and studies of the relationships between tectonics, volcanism and sedimentation (Gennesseaux et al., 1989). A first synthetic map (Sartori et al., 1982) was based on data obtained on cored samples during drillings and on lavas dredged or sampled *in situ* in the western Mediterranean. Additional data include (i) the first K-Ar dating of dredged lavas from the "Tristanite Ridge" (Réhault, 1981; Réhault et al., 1985), (ii) K-Ar and ^{40}Ar-^{39}Ar ages of columnar-jointed lavas in SW Corsica (Bellon et al., 1985), (iii) dating of submarine volcanoes (Monte Doria complex and Genoa Gulf central volcano), south of Genoa Gulf (Fanucci et al., 1993), and finally (iv) the trace element geochemistry and ^{40}Ar-^{39}Ar ages of calc-alkaline volcanism in southwest Corsica (Rossi et al., 1998).

New multi-beam bathymetric coverage of the Ligurian Sea resulted in a better mapping of the northwestern and southwestern Corsica volcanic fields (Réhault et al., 1998; Guennoc et al., 1998). These data were gathered and partly reinterpreted by Gattacceca (2001) and Rollet et al. (2002). The present paper is based on 25 new ages (whole rock K-Ar conventional ones and mineral ^{40}Ar-^{39}Ar ages), 22 geochemical analyses of major and trace elements by ICP-AES, and microprobe analyses of primary clinopyroxenes from 26 lavas. The data obtained on offshore sites and samples collected during five main cruises, Geomed IV and Marsili in 1974, Cyaligure in 1977, Marco in 1995 and Cylice in 1997, are shown in Table 1 and Fig. 2.

3 – Geochronology, petrology and geochemistry of the offshore volcanism

3. 1. Alteration effects

Many submarine rocks display typical alteration features including the development of iron oxides and hydroxides, ferromagnesian or carbonated coatings. Black Mn oxyhydroxide-coated carbonates and thin ferromagnesian films, with later organic carbonate coatings, have been observed on the Asinara Gulf lavas (Castelsardo Canyon). Rocks dredged on the "Tristanite Ridge" (e.g. GIV DR 10, Geomed IV cruise) contain frequent "serpulid polychaete" among a diversified fauna of Pleistocene corals, sponges and gorgonarians (Zibrowius, 1980). Hydrothermal carbonate vesicles are common in Cyl 22-04 and Cyl 22-03 lavas from Monte Doria (-1588 m; Fig. 2).

Alteration processes led to important changes of major and trace elements as discussed in section 3.3. Such a strong alteration is a major problem for obtaining significant K-Ar and ^{40}Ar-^{39}Ar ages. Many of the dated samples display obvious features of a well developed low-temperature alteration, with iron oxides and hydroxides, clays and carbonates invading the cores of samples. Numerous occurrences of celadonite, zeolites and clay-type minerals suggest that the secondary development of these minerals was favoured either by processes, which took place just after magma emplacement or by gradual alteration by seawater over a large time span.

3.2. Dating the volcanic rocks

3.2.1 K-Ar dating procedures

Twenty five lavas have been considered for dating purposes. Among these, 14 samples display a loss on ignition (LOI) lower than 6 wt. % while 8 of them have a higher LOI. Nevertheless, we attempted to date the latter samples because of their interesting geological position.

Potassium-argon ages were measured in Brest (UBO, Université de Bretagne Occidentale) on whole-rock lavas. Grains of rocks 0.3 to 0.15 mm in size were prepared after crushing and subsequent sieving of the solid samples. One aliquot of grains was powdered in an agate grinder for chemical attack of around 0.1 g of powder by 4 cc of hydrofluoric acid, before its analysis of K content by AAS (Atomic Absorption Spectrometry). A second aliquot of grains was reserved for argon analysis. About 0.3 g to 1 g of grains were heated and fused under vacuum in a molybdenum crucible, using a high frequency generator. Released gases during this step of the process were cleaned successively on three quartz traps containing titanium sponge during their decreasing temperature during 10 minutes, from 800°C to the ambient one, and at the final step

the remaining gas fraction was ultra-purified with an Al-Zr SAES getter. Isotopic composition of argon and concentration of $^{40}Ar_R$ were measured in a stainless steel mass spectrometer with a 180° geometry. Isotopic dilution was realized with the fusion step, using for this process precisely concentrations of ^{38}Ar buried as ions in aluminium targets (Bellon et al., 1981).

Resulting ages, listed in Tables 1 and 2, are calculated using Steiger and Jäger's (1977) constants and errors, following the equation of Mahood and Drake (1982). Results for the 8 samples, which have a high LOI are underlined in Tables 1 and 2, and must be interpreted with caution. We have crosschecked some of these whole-rock K-Ar conventional ages with ^{40}Ar-^{39}Ar data carried on carefully separated grain minerals (plagioclase, amphibole and biotite) from these lavas. The irradiation technique of grains has led to ^{40}Ar-^{39}Ar results, which are presented in Tables 1 and 3 and in Fig. 3.

3.2.2 ^{40}Ar-^{39}Ar analytical procedures

Single grains of amphibole and biotite used for the experiments were carefully handpicked under a binocular microscope from the 0.5-1mm fraction of the crushed rock sample Cyl 02-1. The plagioclase crystals (Cyl 03-1 and Cyl 07-3) were separated by the classical methods (magnetic separator and heavy liquids) and the two final mineral separates (in the range 125-160 µm) were obtained by handpicking under a binocular microscope. The samples were wrapped in Al or Cu foils to form small packets (11x11mm.). These packets were staked up to compose a pile in which packets of flux monitors were inserted every 8 to 10 samples. The stack, put in an irradiation can, was irradiated for 5 hours at the McMaster reactor (Hamilton, Canada) with a total flux of 6.4×10^{17} n.cm^{-2}. The irradiation standard was the sanidine Fish-Canyon with an age of 28.02 ± 0.28 Ma (Renne et al., 1998). This sample arrangement allows monitoring the flux gradient with a precision as low as ± 0.2%.

The step-heating experiment procedure was described in details by Ruffet et al. (1991, 1995). The single grains were heated for analyses with a continuous argon-ion laser. Analyses were performed with a VG3600 Mass Spectrometer. Blanks were performed routinely each first or third run, and then subtracted from the subsequent sample gas fractions. Typical blank values were in the range $3.7 \times 10^{-13} < M/e_{40} < 7.8 \times 10^{-13}$, $2.0 \times 10^{-14} < M/e_{39} < 1.6 \times 10^{-13}$, $1.1 \times 10^{-13} < M/e_{37} < 1.23 \times 10^{-13}$ and $3.9 \times 10^{-14} < M/e_{36} < 6.8 \times 10^{-14}$ cm^{-3} STP.

Argon gas was extracted from bulk samples in a double vacuum HF furnace and purified in a line including two SAES GP 50W getters with St101® zirconium-aluminium alloy operating at 400°C and a -95°C cold trap. Corresponding analyses were performed with a mass spectrometer which consists of a 120° M.A.S.S.E.® tube, a Bäur Signer® source and an SEV 217® electron-multiplier (total gain: 5×10^{12}).

To define a plateau age (Fig. 3), a minimum of three consecutive steps was considered,

corresponding to a minimum of 70% of the total $^{39}Ar_K$ released, and the individual fraction ages should agree within 2 sigma with the integrated age of the plateau segment.

3.2.3. Age results (Tables 1, 2 and 3)

For a better comparison of the results obtained by whole-rock K-Ar dating and by ^{40}Ar-^{39}Ar dating on separated minerals, they are presented in the text and the figures with one decimal and ± two sigma error, while they are listed in Tables 1, 2 and 3 with two decimals and ± one sigma error.

Offshore volcanics in southwestern Corsica display ages ranging between 21 and 7 Ma. This cluster is further split into four groups, 21 to 18 Ma, 16 to 14 Ma, ca 12 Ma, and finally ca 8 Ma. The volcanic complex is located at sites 3, 1 and 2 (Fig. 2a) in the Canyon des Moines, the Castelsardo Canyon and at Monte Paoli, west of the N20°W trending fault bordering the Bonifacio straits. These represent at least four volcanic events, at 20.7 ± 1.0 Ma to 19.2 ± 0.9 Ma (Canyon des Moines), at 18.5 ± 2 Ma to 16.5 ± 1.0 Ma (Canyon des Moines and Monte Paoli) and finally at 14 ± 0.8 Ma (Castelsardo) and 11.7 ± 2.2 Ma (Canyon des Moines).

Valinco Canyon, Ajaccio and Propriano Highs were loci of volcanic events at 20.6 ± 1.0 Ma (^{40}Ar-^{39}Ar age on plagioclase), and between 16.1 ± 0.80 Ma (^{40}Ar-^{39}Ar age on amphibole) and 14.6 ± 0.7 Ma (whole rock K-Ar age). These data are in agreement with intermediate ^{40}Ar-^{39}Ar plateau ages of 15.8 ± 0.2 Ma and 15.6 ± 0.1 Ma measured on separated biotites and amphiboles. A more recent event is documented by two whole rock ages of 12.8 ± 3.7 Ma and 11.9 ± 0.6 Ma, respectively. Volcanics sampled in northwestern Corsica on the slope of Cap Corse yielded an age of 19.6 ± 3.0 Ma.

Surprisingly, the "Tristanite Ridge" samples gave three different results for similar K-rich compositions: the "tristanite" (potassic benmoreite) lava first dated at 18.0 ± 1.0 Ma (Réhault et al., 1984) is in fact a trachyte. K-Ar dating of two related lavas (this study) sampled by diving on the same volcano yielded 12.8 ± 0.6 and 12.4 ± 0.6 Ma, respectively. An older age of 43 ± 2.3 Ma was also measured on a lava collected on the neighbouring volcano.

Monte Doria seamounts yielded ages ranging from 11.4 ± 1.4 Ma (shoshonitic lava; Fanucci et al., 1993) to 7.3 ± 1.4 Ma, with intermediate ages between 9.2 and 7.5 Ma within the error bars (8.6 ± 0.6 Ma yielded by a Cylice basalt and 8.4 ± 0.6 Ma by a Marco basalt). Finally, a lava from Genoa Gulf Central Volcano was dated at 14.8 ± 2.8 Ma.

3.3. Main geochemical features of the studied lavas

Major and trace element analyses are listed in Tables 4a (SW Corsica lavas) and 4b (NW Corsica lavas and references for geochemical comparisons). Results were obtained at Brest by

Inductively Coupled Plasma - Atomic Emission Spectrometry (ICP-AES) on solutions of agate-grinded powders. AC-E, BE-N, JB-2 and PM-S standards were used for calibration tests. Relative standard deviations are 2% for major oxides except for MnO and P_2O_5, and less than 5% for trace elements. Details of the analytical techniques are given by Cotten et al., (1995).

Reference onshore samples listed in Table 4 are two K-rich basaltic andesites collected near Nice (Tourettes and Villa Maure) and two quartz-bearing microdiorites or "esterellites" (Le Drammont quarry) and a basalt collected north of Toulon (Coulon, 1977; Dautria and Liotard, 1990). Quartz-bearing microdiorites display the high silica and alumina contents, high Na_2O/K_2O ratios and very low heavy rare earth element (HREE) and Y contents considered typical of adakites (Defant and Drummond, 1990; Defant et al., 1991, 1992; Martin, 1999; Martin et al., 2005; Richards and Kerrich, 2007; Moyen, 2009). However, their Sr/Y and La/Yb ratios (43 and 26-32, respectively), although higher than those of "regular" calc-alkaline lavas, are lower than those of calculated or experimental slab melts (>80 and >30, respectively; see Jégo et al., 2005; Moyen, 2009 and references therein) and their Sr contents are also lower than those of the former. Therefore, they can be termed "intermediate" adakites (Sajona et al., 2000; Jégo et al., 2005; Calmus et al., 2008, 2011).

Some offshore lavas have LOI contents reaching up to 22 wt.%. These high LOI are mainly due to the presence of carbonates filling up vesicles or developed as veinlets resulting from the circulation of hydrothermal fluids. These samples usually display low SiO_2 contents together with high Al_2O_3 (e.g. 41 and 22 wt.%, respectively, for an altered basaltic andesite). The variation of silica contents versus LOI in the lavas is shown in Fig. 4. Silica contents decrease drastically when LOI increases, as illustrated by lavas from Propriano High (site 6) or by those of the trachytes from the "Tristanite Ridge" (site 7). Such a negative correlation is characteristic of low-temperature and hydrothermal alteration by seawater (Cann, 1979; Alt, 1995).

The compositions of the less altered offshore lavas range from basaltic to intermediate and acidic (60 to 70 wt. % SiO_2). Most basalts, basaltic andesites and andesites display relatively low TiO_2 and P_2O_5 contents (< 1.3 wt.% and < 0.36 wt.%, respectively) consistent with a calc-alkaline signature. A rather fresh adakite depleted in HREE and Y (Propriano High, sample Cyl 02-02, Table 4) was also analysed.

Multielement patterns normalised to the primitive mantle of Sun and McDonough, 1989 are shown for lavas collected within the southwestern Corsica volcanic field (Figs. 5a and 5b), and from the northwestern field: Cap Corse and reference samples (Fig. 5c), Doria seamounts lavas (Fig. 5d) and Tristanite Ridge lavas (Fig. 5e). A comparison of patterns for offshore lavas with patterns of selected onshore lavas, taken as references (Figs. 5c and 5d) because of their low LOI, leads us to the conclusion that the REE and the high field strength elements (HFSE: Nb, Zr, Ti) were relatively immobile during the

alteration processes (Cann, 1979; Alt, 1995). On the other hand, the large ion lithophile elements (LILE: Rb, Ba, Sr) show large variations and erratic behaviour in Fig. 5 plots, related to their mobility during alteration.

The multielement patterns of 6 lavas from Castelsardo, Monte Paoli, Valinco, Ajaccio and Propriano sites are shown in Fig. 5a. All of them display a significant negative Nb anomaly typical of subduction-related magmas. Their patterns are variably enriched, as La/Yb normalised ratios range from 4 to 25.

Two different types of patterns of subduction-related lavas (negative Nb anomaly) are shown in Fig. 5b. Canyon des Moines lavas display medium-K calc-alkaline patterns while the two Propriano samples have very steep REE and multielement patterns, with very high Sr contents (945 and 795 ppm) and La/Yb and Sr/Y ratios (68-72 and 31-36, respectively) which plot within the range of adakites. The latter patterns are similar to those of onshore adakites from Le Drammont (77S4F and Est 96-2), shown in Fig. 5c together with that of calc-alkaline lava from the Cap Corse. However, the two Propriano samples are more K-rich than most adakites (Table 4a; Moyen, 2009), a feature, which could be due to post-magmatic processes.

In Fig. 5d, the patterns of Doria seamounts and of Genoa Gulf Central Volcano lavas are very similar to each other. By comparison with diagrams 5a, 5b and 5c, they display a less pronounced negative Nb anomaly. These K-rich "shoshonitic" lavas differ, however, from the Toulon alkali basalt, which shows a positive Nb anomaly and lower potassium content. Finally, the patterns of andesitic and trachytic lavas collected from the "Tristanite Ridge" (site 7) are shown in Fig. 5e. All these samples are K-rich and display a negative Sr anomaly, possibly indicative of plagioclase fractionation.

3. 4. Clinopyroxene compositions

Chemical compositions (Table 5) of primary clinopyroxene phenocrysts and microphenocrysts from 26 mafic and intermediate lavas have been analysed using the Cameca SX 100 microprobe in BRGM (Orléans, France) and the Cameca SX 50 and Cameca SX 100 microprobes in Brest. They have been plotted in the Leterrier et al., (1982) Ti *versus* Ca+Na discrimination diagram (Fig. 6) and compositions are given in Table 5. The pyroxenes from most southwestern Corsica studied lavas (Fig. 6d) plot in the sub-alkalic field, while some are clearly located in the alkalic field pyroxenes from Cap Corse lavas (Fig. 6b) are clustered in the sub-alkalic field. The pyroxenes of lavas sampled from the Tristanite Ridge (Fig. 6c) plot in both fields. Finally, most analyses of Monte Doria clinopyroxenes plot within the alkalic field (Fig. 6d).

3.5. Minerals compositions

Microprobe analyses of clinopyroxenes, feldspars, amphiboles, biotites, and oxides are detailed in Appendix 1 (Data repository), where can be successively found: (1) selected analyses of clinopyroxenes and feldspars in basaltic andesites collected at sites 1, 3 and 12; (2) selected analyses of clinopyroxenes and feldspars in shoshonitic and alkaline lavas collected at sites 9 and 10; and (3) selected analyses of feldspars, biotites, amphiboles, and oxides in adakitic andesites collected at site 6.

4- Integrated presentation of offshore Corsica volcanic fields: geology, K-Ar ages and geochemistry

4.1. The southwestern Corsica volcanic field

Sites of sampling (Table 1 and Fig 2a) are located on a thinned continental crust (Morelli, 1974; Gennessseaux et al., 1989; Gueguen, 1995; Rollet et al., 2002). Previous surveys (Bayer et al., 1973) predicted volcanic occurrences along two main linear ridges well displayed on magnetic anomalies maps of Galdeano and Rossignol (1977). More recent seismic lines and sampling informations suggest the lack of continuous magmatism (Guennoc et al., 1998; Réhault et al., 1998). The linear trends of volcanic centres probably mark the locations of tear faults. Offshore, the southwest Corsica area presents northwest-southeast elongated transverse anomalies. Although some reliefs of the acoustic basement can be associated with magnetic anomalies, there is rarely a direct relationship between these two features. Indeed, (i) most of the magnetic sources are located at depth within the crust, and (ii) shallow basement reliefs and exposed submarine volcanic units appear to be non-magnetic, as confirmed by the very low or non-magnetic susceptibility of the collected samples.

Further to the north, up to 42°N, several isolated volcanic seamounts oriented N10° to N20°E have recently been identified (Fig. 2a). The eastern limit of this volcanic field is located along the northern to northwestern – southern to southeastern fault bordering the Bonifacio continental shelf (Guennoc et al., 2004). There, volcanic intrusions within the whole Miocene series have been detected on seismic profiles and shallow volcanic seamounts are visible at the western edge of the shelf.

During Marco and Cylice cruises, additional samplings and observations were performed on reliefs located along the three main north-west - south-east axes (Fig. 2a), on the northern edge of the area, and on isolated seamounts more easily accessible along the flanks of major canyons: Castelsardo, Moines, Propriano, Valinco and Ajaccio canyons (Table 1, Fig. 2a). Magmatic

units observed during divings are made up of massive rocks, often fractured. They were somewhat difficult to sample because of cementation by oxides coating and/or thick carbonate crust and organic crust. In a few areas, on some seamounts and on the flanks of the Canyon des Moines, the layered volcanic structures evidenced on seismic lines resulted from submarine emissions as shown by ropy lavas or pillow lavas and columnar-jointed structures observed during dives Cya 77-35 (Bellon et al., 1985) and Cyl 07. Pyroclastic deposits interbedded within Miocene sediments have been observed in the upper part of the margin area. From seismic profiles, widely extended and thick volcano-detritic deposits are thought to occur around volcanic seamounts. All these observations point out to a significant magmatic event, which occurred during a relatively short period of time within the Lower Miocene on the southwestern Corsica margin. The Balistra and Tre Paduli ignimbritic tuffs located in southern Corsica (Fig. 2) (Ottaviani-Spella et al., 2001) can be reasonably considered as remnants of this event.

4.1.1 Site 1 - Castelsardo Canyon

Most of the lavas collected at -1859 and -1785 m from the sharp northern flank of this canyon are porphyritic basalts, which contain plagioclase (An_{72-52}) and augite phenocrysts, with or without altered olivine. Some lavas show a large amount of secondary calcite and quartz (Cyl 01-03) and their vesicles are filled by smectites, zeolites and celadonite. The multielement pattern of MA 74 DR 05 (Fig. 5a) show a negative Nb anomaly typical of calc-alkaline lavas and a moderate enrichment in the most incompatible elements, with a La/Yb normalized ratio of 4.

These lavas, dated on two different fractions at 14 ± 0.8 and 13.7 ± 1.8 Ma respectively, are nearly contemporaneous basaltic andesite flows overlaying the granitic basement (supposed of Variscan age), as attested by the seven samples of monzodiorite, monzogranite and leuco-monzogranite collected in the course of Cylice cruise. In their vicinity, pelagic calcareous sediments were collected on the flanks of the canyon using a Kullenberg-type piston corer. These sediments contain no volcanic ashes nor detrital fragments. Planctonic foraminiferas (Globorotalia acostaensis) and others from Miozea group (Genesseaux et al., 1974) indicate a Lower Tortonian age for this sub-horizontal level. Therefore, these onlapping sediments were deposited about 3 My after these volcanic emissions.

4.1.2 Site 2 - Monte Paoli

Monte Paoli, a large sub-circular relief uprising to -1600 m (about 20 km in basal diametre and 8 km near its top), was visited during the Cyaligure Cruise in 1977. Because the flanks were highly coated by thick (ca 10 to 20 cm) Fe-Mn crusts, no volcanic sample was collected during submarine operations despite two dives. However, volcanic samples (Cya 77 DR02-a2 and a)

were dredged at -1980 and -1950 m on its southern and western flanks. These basaltic andesites show typical negative Nb anomalies, and relatively flat multielement patterns (Fig. 5a). They yielded two different K-Ar ages of respectively 18.3 ± 1.0 and 15.9 ± 0.8 Ma. The older age is tentatively preferred to the younger one because of the lower alteration of the sample. Nevertheless this age might be slightly rejuvenated.

4.1.3 Site 3 - Canyon des Moines

Samples Cyl 07-11, 07-10, (coarse-grained doleritic basalts), Cyl 07-07 (highly porphyritic basalt) and Cyl 07-03 (porphyritic basaltic andesite) were collected by the Cyana submersible along the northern side of Canyon des Moines incision, at depths ranging from -1200 and -1000 m. They complete a previous sampling made during Cyana dive in 1977, during which a columnar-jointed lava (Cya 77-35-03) was collected at -1682 m (Bellon et al, 1985). They contain plagioclase (An_{72-52}) and augite phenocrysts, with generally altered olivine. Their trace elements patterns (Fig. 5b) show a typical negative Nb anomaly, $(La/Yb)_N$ ratios of 4 to 5, and Rb, Ba and K abundances about 30 times higher than the primitive mantle estimates. These features are consistent with a medium-K calc-alkaline signature (Gill, 1981). Four whole-rock ages and two ^{40}Ar-^{39}Ar ages for separated plagioclases have been performed on collected lavas. Two whole-rock ages of respectively 19.4 ± 0.9 Ma (Cyl 07-11) and 19.2 ± 0.9 Ma (Cyl 07-10) were measured on lavas located at -980-983 m. They have LOI < 2.3 wt.% and contain respectively 2.58 and 2.39 wt.% of K_2O. A plateau age of 20.7 ± 0.1 Ma has been defined for separated plagioclases from Cyl 07-03, a porphyritic basalt collected at -1104 m. Fig. 3 shows its spectrum shape with a slight and regular increase of apparent ages from the low to the intermediate temperature steps. The sizeable error bars calculated for this sample are directly related to its high measured $^{37}Ar_{Ca}/^{39}Ar_K$ ratios. A significantly younger whole-rock age of 11.7 ± 2.2 Ma has been obtained for Cyl 07-07, located slightly deeper at –1137 m. The columnar-jointed Cya 77-35 03 basalt (Bellon et al., 1985), collected at -1682 m, yielded a whole rock age of 18.5 ± 2.0 Ma. ^{40}Ar-^{39}Ar dating on plagioclase separates from this latter sample, gave a plateau age of 16.5 ± 0.5 Ma for 80 % of extracted ^{39}Ar. As a consequence, a preferred crystallization age of 16.5 Ma is proposed for sample Cya 77-35 03 after evaluation and substracting excess argon.

The interpretation of seismic lines indicates that all these volcanic samples are from the main volcanic unit interfingered within a sedimentary sequence older than Messinian. According to our results, this volcanic pile resulted from successive emissions, including at least one possible subaerial event attested by the occurrence of columnar-jointed basaltic flows. We conclude that three different events occurred at ca. 20-19 Ma, 16.5 Ma, and finally around 12 Ma. The depths of the studied lavas are not correlated with their respective ages. Indeed, sample Cyl 07-07

dated at 11.7 ± 2.2 Ma at -1137 m is deeper than basalt (Cyl 07-03) at -1104 m dated at 20.7 ± 0.1 Ma, a nearly common rule in the building of volcanic edifices.

4.1.4 Site 4 - Valinco Canyon

The basaltic andesite sample Cyl 03-01 was collected from the south flank of the canyon at the edge of a linear N130°E trending ridge. Its relatively smooth multielement pattern (Fig. 5a) and its primary pyroxenes plotting in the sub-alkalic field (Fig. 6a) are consistent with a medium-K calc-alkaline signature. Plagioclase separated from this sample yielded a "plateau" age of 20.6 ± 1.0 Ma. Its spectra shape (Fig. 3) shows a slight and regular increase of apparent ages from the low to the intermediate temperature steps. The flat segments defined by apparent ages in the high temperature steps are correlated with rather constant $^{37}Ar_{Ca}/^{39}Ar_{K}$ ratios (# Ca/K ratio). This fact suggests a degassing of pure plagioclase phases. This age overlaps with that determined for plagioclases from the porphyritic basalt from Canyon des Moines (Cyl 07-03 at 20.7 Ma).

4.1.5 Site 5 - Ajaccio High

Basaltic andesite Marco DR06-08 (LOI = 11.85 wt.%; K_2O = 0.47 wt.%) yielded a whole rock age of 12.8 ± 3.6 Ma. It was sampled at -1700 m from a large volcano with numerous lava flows and volcanoclastics interlayered within sediments. A nearly similar age (12.4 Ma) has been measured for the last medium K-volcanism (Cyl 07-07; K2O = 0,79 %) in Canyon des Moines. This edifice is presently isolated by several canyon incisions.

4.1.6 Site 6 - Propriano High

This volcano rises from the abyssal plain, merging out from a very thick pile of sediments at -2700 to -2000 m on the southern flank of Propriano Canyon, at the crossing of Valinco, Propriano and Canyon des Moines. Three lavas taken from this edifice have been analyzed: two basaltic andesites, Cyl 02-01 (this study) and Marco Dr 02 by Rossi et al. (1998), and an andesite, Cyl 02-02 (this study). These lavas are characterized by low HREE and Y contents together with high Sr/Y and La/Yb ratios (Fig. 5a, b). While the two basaltic andesites have high LOI, sample Cyl 02-02 is rather fresh (LOI = 1.36 wt.%, Table 4a). This sample has preserved the characteristic mineralogical and geochemical (major and trace elements) signature of silica-rich adakites (Defant and Drummond, 1990; Maury et al., 1996; Martin, 1999), although it is more potassic and less rich in Cr and Ni than most of them. The two others might be classified as low-silica adakites (Martin et al., 2005; Moyen, 2009) but alteration effects largely overprint their geochemical signature. This is the first occurence of adakitic lavas reported for the Corsica margin

The K-Ar whole-rock age of Cyl 02-02 is 14.6 ± 0.7 Ma, while those of two amphiboles and

one biotite from Cyl 02-01 are 15.6 ± 0.2 and 15.8 ± 0.5 Ma, respectively (Fig. 3). Cyl 02-02 is a porphyritic lava containing zoned plagioclases (An_{62-42}), biotite (X_{Mg} = 64-60), magnesio-hornblende (X_{Mg} = 78-70) (see appendix) , rare quartz, apatite and zircon. It is similar, although less altered, to the andesite Dr 02-1a, dredged during the Marco cruise from this edifice, dated at 16.1 ± 0.4 Ma (^{40}Ar-^{39}Ar plateau age for amphiboles, Rossi et al., 1998). A nearly similar plateau age of 16.5 Ma had been obtained for Cya 77-35 03 lava, dredged in the Canyon des Moines (Bellon et al., 1985). The concordance between low temperature apparent ages displayed by plagioclase Cyl 03-1 and biotite and amphibole "plateau" ages from sample Cyl 02-1 is worth noting. This cluster of similar ages strongly suggests the presence of a new volcanic event at ca. 16 Ma, i.e. during the last stages of the Ligurian Basin opening (Gattacceca et al., 2007).

4.2. Northwestern Corsica margin and the Liguria Basin volcanic fields

A relatively widespread magmatism in the Liguria Basin is assumed on the basis of the observed magnetic anomalies (Galdeano et Rossignol, 1977; Réhault, 1981; Réhault et al., 1985; Rollet et al., 2002). Sites of sampling and investigation are listed in Table 1 and located in Fig.2a and 2b. Isolated large magnetic anomalies were observed at the foot of the northern Provence margin, south of Antibes and Cap d'Ail. To the north, in the Ligurian Basin, an elongated transverse anomaly is stretching the Liguria Basin from Cap Mele to north of Cap Corse.

4.2.1. Site 7 - The "Tristanite Ridge"

Direct evidence of Tertiary magmatism within the central basin has been so far restricted to a linear relief, the so-called "Tristanite Ridge", merging up to about -1900 m from the deep sea-bottom at -2550 m in the northern part of the Liguria Basin. This large elongated magnetic structure, sampled at sites 7 a, b, c and d, (Fig. 2a and 2b), is prolongated south-westwards by buried seamounts (median relief, Fig 2a). Lateral erosional surfaces pointed on seismic lines suggest that it was an archipelago during Messinian times (Réhault, 1981; Gennesseaux et al., 1989; Réhault et al., 1998; Gueguen et al., 1998; Rollet et al., 2002). Structurally, this ridge is lying along the external border of the Corsica deep thinned margin, towards the central part of the Basin.

Three separate culminating reliefs from this ridge were sampled (Fig.2a and 2b). The most south western relief rises from -2550 m in the central deep Liguria Basin. Dredging at site 7a yielded a volcanic white tuff MA 74 DR 01 near its base (-2470 m). At site 7b, a porphyritic

andesitic lava was collected near its base (Cyl 20-01), and a volcanic white tuff was sampled near its top (Cyl 20-02 at -2440 m and Cyl 20-04 at -2285 m). At site 7c, a light green lava, G IV DR 11a, was dredged on the western flank of the intermediate relief. At site 7d, the northeasternmost relief only yielded a brownish microgranular carbonate (MA 74 DR02), thinly coated with Fe-Mn oxides. Submarine photographic surveys evidence numerous solitary corals fixed on the outcrops.

Lava MA 74 DR 01 shows an irregular shape coated by a thin Fe-Mg carbonated crust, associated with solitary corals; its fresher broken face presented a white and laminated "tuff" that was named at that time "tristanite" according to its high potassium andesitic to trachytic composition (Table 1). We carefully separated this sample in two parts, the central part (core) and the outer one (rim) to check the potential effects of alteration. Very high concentrations of K_2O (up to 7 wt.%) together with those of Rb (up to 300 ppm) are characteristic of these rocks. However, microprobe data suggest that they are partly due to K-rich post-magmatic minerals. The K-Ar ages measured for the rim (15.7 Ma) and the core (18.0 Ma) of this sample differ significantly, the younger age being yielded by the most altered analysed fraction (i.e. the rim). Thus, the core age of 18 Ma is considered as the most realistic.

The porphyritic andesite Cyl 20-01 collected at site 7 b contains phenocrysts of plagioclase (An_{53-33}), diopside, rare amphibole and microlites of potassic feldspar (Or_{65}) set in a variably altered groundmass. Its high K_2O content (5.14 wt.%) is considered as a primary characteristic of the magma. The whole rock fraction yielded an age of 12.8 ± 0.3 Ma.

The K-rich Cyl 20-02 (K_2O = 7.55 wt.%) and rather fresh (LOI = 2.81 wt.%) acidic tuff (SiO_2= 63.6 wt.%) bears plagioclases (An_{54-41}), potassic feldspar (Or_{74-65}), biotite (X_{Mg} = 38) and quartz. It plots within the trachytic field in the total-alkali-silica diagram of Le Bas et al. (1986) (not shown). Its whole-rock K-Ar age, 12.4 ± 0.3 Ma, is very similar to the age of the K-rich andesite Cyl 20-01.

The well-rounded block, GIV DR 11a, showing a fluidal texture, dredged at site 7c, is composed of plagioclase phenocrysts up to 2 mm in size and ghosts of ferromagnesian minerals up to 0.2 to 0.5 mm, set in crypto-crystalline matrix containing post-magmatic minerals. A much older age of 43 ± 2.3 Ma was measured on this lava. This result can be compared with the age of the Calabona microdiorite in Sardinia dated at 38.3 Ma (plateau age; Lustrino et al., 2009). This age can be also compared with the ^{40}Ar-^{39}Ar plateau age of 40 ± 2 Ma (Maluski, 1977) obtained on phengites from the "Schistes lustrés" unit located in the Cap Corse region. Another explanation would be a possible thermal rejuvenation. All these interpretations are consistent with the hypothesis that the basement of the "Tristanite Ridge" might be similar to that of the Corsican ophiolitic series.

4.2.2. Sites 8, 9 and 10: Monte Doria volcanic complex

Monte Doria volcanic complex (Fig. 2a), approximately 40 km in length and 25 km in width, consists of a huge seamount (site 9) and parasitic volcanoes located either east of the main centre (site 8) or on it (site 10).

At site 9, eight samples were collected from 2500 to 780 m, along the sharp most southern NW-SE trending scarp. The base was sampled by dredging, the medium part by diving and the highest lavas have been piston-cored near the summit. A pile of pillow-shaped lava flows, the individual thickness of which decreases upwards, was observed during divings Cyl 21 and 22. No direct observation was made at site 10, near the centre of the complex, but highly vesicular lavas dredged nearby attest the submarine outpouring of magma at low to moderate depths.

At site 8, submarine flows were sampled by Fanucci et al., (1993) along the western flank of La Spezia canyon, from the Monte Doria eastern flank. A K-Ar age of 11.4 ± 1.4 Ma has been measured for a separated biotite from this shoshonitic lava (Fanucci et al., 1993).

At site 9, most of the sampled lavas are porphyritic olivine basalts with phenocrysts of plagioclase (An_{65-53}) and diopside such as in Cyl 22 basalts (see appendix). An age of 8.6 ± 0.6 Ma, rather close to the ages of 7 ± 0.5 and 6.3 ± 0.4 Ma of the Toulon alkali basalts, was measured on the K-rich basalt Cyl 22-05, collected from the Monte Doria southern flank. This sample displays a positive Nb anomaly (Table 4b and Fig. 5e) consistent with an alkali basaltic affinity. Finally, in Monte Doria centre, at site 10, whole-rock ages obtained on untreated and treated grains of a basaltic sample (Marco DR52-06) were 8.4 ± 0.6 Ma and 7.3 ± 1.4 Ma, respectively.

4.2.3. Site 11: Genoa Gulf Central Volcano

North of Monte Doria centre, another large edifice located in the centre of the Genoa Gulf and culminating at nearly - 450 m was dredged during the Marco Cruise. A basalt (Marco Dr 49-03) dredged near the top of this volcano yielded a whole-rock age of 14.8 ± 2.8 Ma.

4.2.4. Site 12 - Cap Corse western steep margin

On the steep northwestern steep Corsica margin, a new volcanic occurrence has been discovered and sampled during the Marco and Cylice cruises (dive Cyl 15). It is located at the tip of an east-west trending promontory, west of the northern edge of Cap Corse (site 12, Fig. 2). The outcrops, observed from -1730 to - 720 m, are made of altered pillowed basalts. Sample Cyl 15-10 yielded an age of 19.6 ± 3.0 Ma, for a K_2O content of 1.57 wt.%. This age fits the climax of volcanic activity in the southwest Corsica margin, particularly in the Canyon des Moines and the bulk of the Sardinia magmatism, around 22-18 Ma (Lustrino et al., 2009, and references therein).

5. Discussion

5.1. Structural reinterpretation of the Corsica-Liguria Basin magmatism

The Ligurian margins and the western and northern Corsica margins were considered for a long time as having a relatively simple and rather homogeneous structure, because of their steepness and narrowness. This area was poorly investigated because of the presence of a thick cover of Upper Miocene evaporites that blankets the deepest external areas, preventing a detailed investigation of the continent-oceanic transition. Geophysical and geological studies (Gennesseaux et Réhault, 1989; Rollet et al., 2002) confirmed the occurrence of two large magmatic areas. They allowed us to define precisely the morphology and the nature of the volcanic basement and revealed the presence of volcanoclastic units beneath the pelagic sediments.

The West Corsica margin segment presents a narrow and rectilinear trend, which parallels the ocean-continent transition (Figs. 1 and 2a). No evidence of magmatism was recognized offshore on this margin between the southwestern Corsica and northwestern Corsica-Liguria volcanic fields (Fig. 2). However, a mafic dike swarm within the Hercynian basement onshore north of Porto (Aghia Campana) has been dated at ca 25-20 Ma from combined fission track and K-Ar, Rb-Sr and Sm-Nd methods (Van Tellingen et al., 1996).

5.1.1. The southwest Corsican magmatic field

The southwest Corsican field represents the northward extension and termination of the Sardinian rift magmatic area (Fig. 1). Most of the isotopic ages (ca. 16-18 Ma) post-date the 21-18 Ma main oceanic spreading period of the Ligurian basin (Gattacceca et al., 2007), and the peak of igneous activity in Sardinia (Lustrino et al., 2009). This late magmatism, as well as the occurrence of faulted Miocene series in the offshore basins, the Sardinia and southwestern Corsica volcanic events, has been related to a second aborted-rifting stage (Réhault et al., 1984a; Thomas et Gennesseaux, 1986; Gattacceca, 2001; Monoghan, 2001; Ferrandini et al., 2003, Oudet et al., 2010).

The southwestern Corsica volcanic field is bounded eastwards by a N-S fault, in the prolongation of the Sardinian rift faults. It is characterised by isolated volcanic seamounts scattered over the rifted and more or less thinned continental crust, as demonstrated by the granite sampled at the foot of large relief in the Castelsardo canyon. Sills and lava flows are also observed beneath the recent sedimentary cover. Around the volcanic centres, extensive dipping

reflectors are interpreted as volcanoclastic series, with possible interbedded lava flows. The specific character of this field is the occurrence of well-expressed northwestern-southeastern trending linear volcanic ridges, which have been detected for a long time because of the associated strong magnetic anomalies. These magmatic and magnetic transverse features most likely represent previous deep transverse/transform faults intersecting the Sardinian-Corsican margin, which would have been reactivated during the Middle Miocene volcanic event.

5.1.2. The Sardinia rift

The Sardinian rift underwent a long calc-alkaline volcanic history beginning around 38 Ma, with a climax around 22-18 Ma during the tensional rifting phase (Lustrino et al., 2009, and references therein). It was followed by a marine transgression and a second episode of fracturation and volcanic emissions during Langhian times (16-15 Ma; Monoghan, 2001). The latter was linked to a restricted prolongation of the Corsica-Sardinia block rotation until ca. 15 Ma (Ferrandini et al., 2003).

5.1.3. The northwestern Corsica volcanic field

Several hypotheses and interpretations of magnetic anomaly patterns have been proposed to account for the extension of oceanic-type crust within the Northern Ligurian sea. Previous studies (Réhault, 1981, Gennesseaux et Réhault, 1989; Gueguen, 1995; Contrucci, 1998; Rollet et al., 2002) proposed that the area extending from the huge Monte Doria composite volcano to the Median massif, hidden by a large sedimentary blanket, and passing through the central “Tristanite Ridge" (Fig. 7), is located at the edge of the thinned continental margins and nearby transverse/transform zones. Especially, Monte Doria is located on the northern - continental side - of the Capo delle Mele - Cap Corse transform fault zone, a major crustal feature linked to a sharp down faulting of Moho. Indeed, an abrupt deepening of 6 kilometres was registered between two shots distant of 3 kilometres during the Geotraverse Project (Galson and Mueller, 1986).

The two major magmatic areas of the Ligurian sea margins are located on the thinned continental crust edges cut by the major Capo delle Mele-Cap Corse transform fault zone. We assume that the emplacement of important volumes of magma emitted here by comparison with other areas (Fig. 7) even after the end of the oceanic spreading, was favoured by such deep faulted and weakened zones of thinned crust. Therefore, the southwestern Corsica-margin's Miocene magmatism lies at the northern edge of an aborted rift, which disrupted the Sardinian block, while the Northern Ligurian margin volcanism is located at the NNE edge of the Ligurian oceanic area. These volcanic events occurred during the last steps of the “oceanisation” of the Ligurian Sea before its transfer to the Tyrrhenian Sea.

5.2. Oligo-Miocene magma types and their tectonic settings

The magmatic rocks investigated in this study can be classified into three main groups, i.e. (i) K-depleted and K-rich calc-alkaline basaltic andesites and andesites, which are the most abundant, (ii) adakite-related lavas such as Cyl 02-02 (site 6), and (iii) alkali basalts and related intermediate and felsic lavas, e.g. trachytes Cyl 20-02 and MA 74 DR 01.

5.2.1. Calc-alkaline magmas

Calc-alkaline lavas erupted in the southwest Liguro-Provençal basin and its margins display the usual mineralogical and geochemical features of subduction-related magmas. Most of these rocks are rich in potassium and plot either in the K-rich calc-alkaline or shoshonitic fields in Peccerillo and Taylor's (1976) diagram (not shown). This relatively K-rich character is a typical feature of circum-Mediterranean magmatism (Wilson et Bianchini, 1999; Lustrino et al., 2011), usually linked to an isotopic signature strongly inherited from continental crust. Although the altered character of most of our submarine K-rich calc-alkaline samples precludes any detailed radiogenic isotope studies, Sr and Nd isotopic data are available for the Ligurian margin calc-alkaline andesites (Galassi, 1995a, b) and the K-rich calc-alkaline lavas from Sardinia (Cioni et al., 1982; Lustrino et al., 2004). They are rather radiogenic in Sr ($^{87}Sr/^{86}Sr$ = 0.7045-0.707) and unradiogenic in Nd ($^{143}Nd/^{144}Nd$ = 0.51235-0.51265). Such a continental crust imprint is usually explained by the chemical contribution of continentally derived subducted sediments combined with shallow-level crustal contamination (Wilson and Bianchini, 1999). The petrogenetic modelling of Sardinia calc-alkaline lavas concludes to their primary derivation from melting of mantle wedge peridotites previously metasomatized by hydrous fluids carrying a sedimentary crustal component (Dostal et al., 1982; Lustrino et al., 2004, 2011).

5.2.2. Adakites

The origin of adakitic magmas is still a matter of hot debate. It has been attributed to the partial melting of thickened continental crust or to moderate- or high-pressure fractionation of andesitic liquids (see Jégo et al., 2005; Richards and Kerrich, 2007; Moyen, 2009 and references therein). Many authors (Martin et al., 2005; Maury et al., 2009; Moyen, 2009) consider that typical (silica-rich) adakites derive from 10-35 % melting of MORB-type basalts converted into garnet amphibolites or eclogites (Defant and Drummond, 1990). Such a melting requires temperatures higher than 800 °C, even in the presence of hydrous fluid, at pressures of ca. 2 GPa (Prouteau et al., 1999). This set of pressure-temperature conditions is usually attained

in cases of subduction of either active oceanic ridges or very young oceanic crust (Defant and Drummond, 1990; Peacock et al., 1994; Martin, 1999; Lagabrielle et al., 2000).

Obviously, this is not a realistic situation for the oceanic lithosphere subducting below the studied area, which is thought to have been either of Alpine Tethysian (Handy et al., 2010, Oudet et al,. 2010) or Mesogean (Carminati et al., 2010) origin, even if we inclined to favour the last one. However, adakites are also known to occur in transient tectonic settings corresponding either to the initiation of subduction of relatively old oceanic crust (Sajona et al., 1993), to the end of its subduction (Sajona et al., 1994; Maury et al., 1996), or to the development of a slab tear or slab window during collision (Pallares et al., 2007; Gasparon et al., 2009; Lustrino et al., 2009; Maury et al., 2009; Calmus et al., 2011).

In such transient P-T regimes, melting of the subducted MORB crust may occur (Peacock et al., 1994) because of the additional heat provided either by the sinking of the edge of the downgoing crust into the hot asthenospheric arc mantle (initiation of subduction), or by the thermal rebound affecting the slab at the end of subduction (Sajona et al., 1994), or near the edges of the slab tear or window (Thorkelson and Breitsprecher, 2005). These situations can apply to Le Drammont adakitic "esterellites" and Propriano High adakites. The emplacement of the "esterellites" could mark the onset of subduction-related magmatic activity in the Ligurian margin. The Propriano High adakites could either mark the end of subduction-related magmatic activity of southwest Corsica margin, or they could be linked to a slab tearing or even slab detachment process.

5.2.3. Alkali basalts and related rocks

The third group, i.e. the alkali basalts and related rocks, is difficult to document because of the highly altered character of the corresponding mafic lavas from the three dredged sites (Monte Doria seamount, South Doria area and northwestern Corsica margin), the alkaline affinity of which is only deduced from their clinopyroxene compositions. The only relatively fresh alkali-rich rock recovered is the trachyte Cyl 20-02, the composition of which is too evolved to allow chemical characterisation of its initial mantle source. Its alkaline affinity, however, is dubious because of its Nb and Zr contents clearly lower than those of "anorogenic trachytes" found, for instance, in Isola del Toro (Lustrino et al., 2007b). The fact that the emplacement of these sodic alkali basalts during the Langhian times seems to immediately post-date the end of the subduction event is not easy to explain in an area where there is no specific indication of the occurrence of a mantle plume. However, similar very rapid transitions from K-rich calk-alkaline toward alkaline basaltic activity has been documented in other parts of the Mediterranean domain e.g. in Tunisia (Halloul, 1989), northern Morocco (El Azzouzi et al., 1999), Oranie (Coulon et al., 2002) and Sardinia (Lustrino et al., 2004, 2007b). Maury et al.

(2000) have interpreted this rapid transition as indicating a slab break-off. Such a process was documented from other lines of evidence by Carminati et al., (1998a, b) and de Boorder et al., (1998) for the Langhian geological evolution of the Maghreb. However, these authors do not mention the possibility of a Langhian breakoff beneath the Liguro-Provençal Basin, originally proposed by Serri et al. (1993). During the breaking-off of the subducted slab, the calc-alkaline magmatism, which derives from the melting of the metasomatized mantle wedge overlying the slab, is progressively replaced by a sodic alkali basaltic magmatism originating from adiabatic partial melting of the hot asthenosphere uprising through the slab window (Davies and von Blanckenburg, 1995; Pallares et al., 2007; Thorkelson et al., 2011).

5.3. Incidences on the geodynamic evolution of the western Mediterranean domains

5.3.1. Regional tectonic framework

It is largely admitted that the Tertiary convergence between Europe and Africa led to north-dipping and northwestern-dipping subductions of the African lithosphere and its precursors beneath the European plate (Cohen, 1980; Réhault, 1981; Réhault et al., 1985; Carminati et al., 2010). Especially, an Oligocene to Early Miocene northwestern- to west-dipping subduction of the Apulia-Adriatic-African lithosphere beneath the Corsica-Sardinia block is considered in most geodynamic reconstructions (Dercourt et al., 1986; Beccaluva et al., 1987, 1994, 2005; Faccenna et al., 1997; Gueguen et al., 1998; Jolivet et al., 1998; Carminati et al., 1998, Gattacceca, 2001; Ferrandini et al., 2003. Lustrino et al., 2009; Carminati et al., 2010, Oudet et al., 2010). During the Middle to Late Miocene, the rollback of the oceanic slab resulted in a passive asthenospheric upwelling in the back-arc domain. It led to the subsequent opening of the Liguro-Provençal Basin and the counter-clockwise rotation of Corsica and Sardinia (Malinverno et al., 1986; Serri et al., 1993; Faccenna et al., 1996; Jolivet et al., 1998; Doglioni et al., 1999; Séranne, 1999; Gattacceca et al., 2007; Lustrino et al., 2009). Some authors, e.g. Serri et al. (1993), proposed that a slab detachment of the oceanic part of the Apulia-Adriatic lithosphere occurred during the Early Miocene. Then, during the Upper Miocene and the Plio-Quaternary, the dominant tectonic regime in the northern part of the Tyrrhenian basin and the northwestern part of the Ligurian basin was extensional (Jolivet et al., 1998 and references therein). It led to the emplacement of numerous magmatic bodies (Serri et al., 1993) and to a high thermal flux in this area (Jemsek et al, 1985, della Vedova et al., 1995). The tomographic images obtained by Carminati et al. (1998) and de Boorder et al. (1998) are consistent with such an evolution. Indeed, they show below the Liguro-Provençal basin negative anomalies at shallow depths, which are consistent with the occurrence of a hot thermal regime (Jemseck, 1988). Our geochemical and chronological data on the magmatic rocks from the Corsica

margin, Algero-Provençal basin and the Ligurian basin allow us to put relatively precise temporal constraints on this tectonic evolution.

5.3.2. Volcanic types and main periods of volcanism off Corsica

Figure 8 shows the plot on four kinematic positions of our age data completed by the mineral ages carried on Corsica-Sardinia lavas (Savelli et al., 1977; Deino et al., 2001; Speranza et al., 2002; Gattacceca et al., 2007; Lustrino et al., 2009; Oudet et al., 2010; Carminati et al., 2010). These kinematic positions are reconstructed at 33.7 to 26 Ma (pre-rotation fit in Rupelian-Early Chattian times), 23 to 20 Ma (end of rifting and incipient rotation period), 19-18 Ma (time of fast rotation), and 15-14 Ma (present-day position after final rotation of the Sardinia-Corsica block, according to timing proposed by Gattaceca et al., (2007) and Oudet et al., (2010). The space and time distribution of magmatic affinities is presented in Fig. 9, where ages are indicated with error bars at the level of two sigma, owing to comparisons with other data from literature.

The Ligurian domain experienced a succession of volcanic events during the Oligo-Miocene Rather than a more or less continuous activity, ages of magmatic activity cluster in several groups and geochemical affinities of magmas evolve from normal calc-alkaline with episodic adakitic lavas and K-rich lavas until shoshonitic magmas: onshore between 33 and 26 Ma, Le Drammont adakitic “esterellites” and calc-alkaline lavas in Tourette, Saint Antonin and la Vanade, Monaco and Biot), and offshore, calc-alkaline occurrences are dated between 21 and 18 Ma (ie 20.6 Ma for minerals and slightly younger, 19.4 - 19.2 Ma, for whole rocks; calc-alkaline lavas and adakites dated at 16 to 14 Ma are more or less contemporaneous with K-rich lavas and shoshonites (Genoa Gulf) and Sisco lamproites in northern Corsica.

Finally, between 14 and 6 Ma, K-rich and shoshonitic lavas erupted in southwestern Corsica and on the “Tristanite Ridge”, accompanied and/or followed onshore by alkali basalts, since 12 Ma in Sardinia and later, 7 to 6 Ma, in Toulonnais.

5.3.3. Proposed geodynamical and tectono-magmatic model for the Corsica-Liguria Basin

After examining the age and the nature of magmatism versus the four kinematic reconstructions, we suggest to distinguish five main geodynamical and tectono-magmatic stages in the evolution of the Ligurian Sea and its margins from Oligocene to Tortonian. The variations in these proposed periods, as well for their number (five instead of four) as their respective durations, are mainly coming from the delay between main geodynamical events and the linked tectono-magmatic effects.

*Stage I (33–31 Ma),*early beginning of rifting, corresponds to the initiation of the subduction of an oceanic plate of either Alpine Tethysian (Handy et al., 2010, Oudet et al., 2010) or

Mesogean (Carminati et al., 2010) origin beneath the European margin, which includes both the present-day Ligurian margin and the Corsica-Sardinia block (Lustrino et al., 2011). Melting of the down-going edge of this oceanic crust in the transient thermal regime linked to subduction initiation (Peacock et al., 1994; Sajona et al., 1993) could have resulted in the emplacement of adakitic magmas (Le Drammont "esterellites"). In the Alps, Saint-Antonin andesites were most likely derived from the melting of the metasomatized mantle overlying the slab.

An alternative tectonic framework to the onset of the oceanic lithosphere subduction would be to consider the former stage of the evolution of the Alps domain during Late Eocene and Oligocene times. It marked the end of the European lithosphere subduction relayed by collisional processes. Geodynamic consequences would have involved the steepening, tearing and finally break-off of the down-going lithosphere, which might have been responsible for the widespread Paleocene magmatism in the western Alps (Boyet et al., 2001), including Corsica at that time.

It continued up to 26 Ma with the main initial phase of rifting of the incipient Liguria back arc basin and the linked calc-alkaline emissions.

Stage II (25-23 Ma) was marked by a following intensive emission of calc-alkaline magmas in the Ligurian margin, whereas calk-alkaline activity continued in Sardinia. The onset of an intra-arc rifting process led to the crustal thinning between the Ligurian margin and the Corsica-Sardinia block and the initiation of the Corsica-Liguria Basin.

Stage III (21-18 Ma) was influenced by a slab roll-back process which led to the steepening of the subducted lithosphere. An asthenospheric upwelling was associated with the fast opening of the whole Liguro-Provençal back-arc basin. Calc-alkaline magmatism occurred both in the northwestern and southwestern Corsica volcanic fields, as well as in the Sardinia rift where large magma volumes were emplaced (Coulon, 1977; Lustrino et al., 2004, 2007a, 2009, 2011), during the rotation of the Corsica-Sardinia block (Gattacceca, 2001; Speranza et al; 2002; Gattacceca et al., 2007). In southern Corsica, paleomagnetic data indicate that the rotation was not completely achieved at 19 Ma (Ferrandini et al., 2003, Oudet et al., 2010).

Stage IV (16-14 Ma). During the Langhian, medium-K and K-rich calk-alkaline magmas 2003) were again emplaced in the southwestern Corsica volcanic field and in Sardinia (Fig. 2). We relate the adakitic lavas collected at site 6 (Propriano High) to the partial melting of subducted oceanic crust at the end of the Corsica Sardinia rotation. We suggest that these emissions were linked either to the end of subduction or to tearings in the slab which allowed a subsequent asthenospheric uprise through the slab windows (Thorkelson and Breitsprecher, 2005; Pallares et al., 2007; Thorkelson et al., 2011). This hypothesis is consistent with the high heat flow regime measured east of the deep basin, near the base of the Corsica margin.

Stage V (14-6 Ma). Calc-alkaline lavas were replaced by K-rich calc-alkaline and shoshonitic

lavas, as commonly observed during the evolution of collision zones involving the opening of slab windows (Davies and von Blanckenburg, 1995). Calc-alkaline and shoshonitic lavas (Fannucci et al., 1993) and sodic alkali olivine basalts were emplaced in the Monte Doria seamounts complex. During the final period of this stage, sodic alkali basaltic volcanism occurred first onshore, with the emission of basalts dated at 12 Ma in Isola del Toro, SW Sardinia (Lustrino et al., 2007b) and 7-6 Ma in the vicinity of Toulon. Then, after the main Messinian crisis, voluminous alkali basalts were emplaced in Sardinia and alkaline seamounts in the Tyrrhenian Sea (Savelli et al., 1986; Beccaluva et al., 1990; Mascle et al., 2004; Lustrino et al., 2007a; Lustrino and Wilson, 2007). Melting of the deep asthenosphere uprising through the slab window below the northwestern Corsica margin might account for this alkali basaltic (OIB-type) volcanism (Thorkelson et al., 2011).

6. Conclusions

From Early Oligocene to late Miocene times, geochemically diverse lavas were emplaced in the Corsica-Liguria Basin and its margins (Fig. 8 and Fig.9). This diversity includes K-depleted calc-alkaline and K-rich calc-alkaline basalts, basaltic andesites and andesites, adakites, shoshonitic basalts and related intermediate/evolved rocks (trachytes), and finally sodic alkali basalts.

We propose that the emplacement of Le Drammont adakites (“esterellites”) at 33-31 Ma marked the onset of the subduction of an old oceanic lithosphere beneath the southern European margin. It was followed until 18 Ma by the emplacement of medium-K and K-rich calc-alkaline lavas in the Ligurian margin (Villeneuve-Loubet), and in the southwestern Corsica margin as well as in Sardinia. This subduction-related volcanic activity ended near 16-15 Ma in the southwestern Corsica margin with the emission of adakite-related lavas (Marco Dr 02, Cyl 02), while K-rich calc-alkaline activity ended in Sardinia at 14 Ma. K-rich calc-alkaline and shoshonitic lavas were, however, emplaced until 8 Ma in the Tristanite Ridge and Monte Doria Complex (Fig.9).

These changes in the subduction-related magmatism may be attributed to the slab rollback process which led to the break-off and sinking of the oceanic lithosphere during the Langhian times. This slab rollback was also responsible for the intra-arc rifting of the European margin, followed by the Burdigalian “oceanic-type” accretion in the back-arc Liguro-Provençal basin. Finally, during the Late Miocene, the deep asthenosphere uprising through the slab window experienced decompression melting, which led to the emplacement of alkali basaltic edifices in the northwestern Corsica margin and the Tyrrhenian Sea as well as onland (Toulon and Sardinia).

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Figure captions

Fig. 1.

The Western Mediterranean area: general physiography from ETOPO2 global relief map, showing the distribution of the main volcanic edifices resting on both a transitional crust-type (roughly limited by the 2,500 m isobaths and thinned continental crust. 1- Hercynian basement; 2- Alpine Corsica series; 3- Balearic basement; 4- Thinned to transitional crust; 5- Oceanic – type crust; 6- Volcanic edifices.

Fig. 2. Location maps of the studied submarine samples. a: maps and isotopic ages of magmatic samples collected from southwestern (sites 1 to 4) and northwestern areas (sites 5 to 11) of the western Corsica margin. Conventional $^{40}K/^{40}Ar$ whole-rock ages are shown in italics, and $^{40}Ar/^{39}Ar$ mineral ages are underlined. Site numbers as in Table 1.b: Location map of the

sampling sites **from** the “Tristanite Ridge”.

Fig. 3.

$^{40}Ar/^{39}Ar$ spectra of five separated minerals (plagioclase Cyl 07-03, Cyl 03-01; amphibole, biotite Cyl 02-01) from western Corsica margin offshore lavas (sites 3, 4 and 6).

Fig. 4.

SiO_2 *vs.* LOI (wt.%) plot showing the negative correlation linked to increasing alteration processes. Numbers for analyses refer to that of sites and samples in Table 1.

1: MA 74 DR 05a; **2**: Cya 77 DR 02-a; **2a** : Cya 77 DR 02-a2; **3a**: Cya 77-35 03; **3b**: Cyl 07-03; **3c**: Cyl 07-11; **3d**: Cyl 07-10; **3e**: Cyl 07-07; **4**: Cyl 03-01; **5**: Marco DR 06-08; **6a**: Cyl 02-01; **6b**: Cyl 02-02; **6c**: Marco DR02-1a: **7a**: Cyl 20-02; **7b** *core*: Ma 74 DR 01; **7b** *rim*: Ma 74 DR 01; **7c**: Cyl 20-01; **9**: Cyl 22-05; **10**: Marco DR 52-06 a; **11**: Marco DR 49-03

Fig. 5.

Primitive mantle-normalised multi-element plots of western Corsica margin offshore magmatism with references to onshore French Ligurian magmatism (diagram 5c). Elements order and normalisation values are from Sun and McDonough (1989). Diagrams 5a and 5b: southwestern Corsica field lavas; diagram 5c: north Corsica volcanic field, Cap Corse and onshore Ligurian magmatism; 5d: northwestern Corsica volcanic field, Tristanite Ridge lavas.

diagram 5e: northwestern Liguria volcanic field, Doria seamounts and Genoa Central Volcano lavas and Toulonnais lavas; diagram

Fig. 6.

Ti *vs* Ca+Na diagrams showing the compositions of primary clinopyroxenes (phenocrysts and microphenocrysts) from offshore mafic and intermediate lavas from the Corsica margin. The separating line between the alkalic field and the sub-alkalic one is from Leterrier et al. (1982). 6a- northwest volcanic field: Monte Doria seamounts.

6b- north Corsica volcanic field: Cap Corse; 6c- northwest Corsica volcanic field: Tristanite Ridge; 6d-southwest Corsica volcanic field;

Fig. 7.

Structural interpretation of retraced from seismic lines Malis 25, crossing the Propriano High (Fig.7a), and Malis 17 (Fig.7b) crossing the “Tristanite Ridge”. They show the locations of the main geological elements, which denote the evolution of the domain in the southwestern part and the northwestern one. Vertical scale in s. twt.(*second, two way travel time*), (for conversion

in m. the measured thickness must be multiplied by the half seismic propagation velocity of each level).

1- Upper Mantle, Vm = 7.8-8.0 km/s. 2- Oceanic-type crust, Vm = 6,5-7.0 km/s. 3- Transitional crust, Vm = 6.4-6.8 km/s. 4- Continental crust, Vm = 5.8-6.4 km/s. 5- Volcanic edifices, Vm = 4-6 km/s.. 6- Lava flows, Vm = 3.2-5 km/s. 7- Miocene marine pelagic sediments, from early Burdigalian up to late Tortonian. 8- Messinian salt layer Vm = 4-4.2 km/s. 9- Messinian upper evaporites, Vm = 3.2-3.5 km/s. 10- reworked volcanic elements, volcanoclastic layers comprising pillows and breccias elements and/or partly interstratified detritals; 11- Plio-Quaternary turbiditic to pelagic series. Vm = 1.8-2.5 km/s. N.B. The dykes framework and alimentation system are hypothetical.

Fig. 8.

Whole rock K-Ar ages (bold italics) and $^{40}Ar/^{39}Ar$ plateau ages of separated minerals (underlined normal characters) from Corsica-Sardinia lavas: plagioclases (this study and Ferrandini et al., 2003; Lustrino et al., 2009;) amphiboles and biotites (this study). All results are plotted in four kinematic reconstructions of Corsica-Sardinia drifting (after Gattacceca et al., 2007 and Oudet et al,. 2010). Remark that some ages are prior or after the period of these reconstructions around 33-30 Ma, 23-20 Ma, 19-18 Ma and 15-14 Ma.

Fig. 9.

Spatial and temporal distribution of Oligo-Miocene magmatism within and around the northwestern Mediterranean Sea.

List of Tables

Table 1. Summary of the main petrologic features and age data for studied volcanics at each site of investigation.

List of sampling cruises.

Geomed IV in 1974, R/V Jean Charcot, recovering of samples by dredging (code sample G IV).

Marsili in 1974, R/V Marsili, recovering of samples by dredging (code sample MA74).

Cyaligure in 1977, R/V Le Noroit, Cyana, recovering of samples by diving and complementary dredging (code sample Cya 77).

Marco cruise in 1995, R/V le Suroit, recovering of samples by dredging (code sample Marco).

Cylice cruise in 1997, R/V l'Atalante, Cyana recovering of samples by deep diving (code sample Cyl).

Table 2. Whole-rock K-Ar ages and analytical parameters for offshore lavas from the southwestern and the northwestern Corsica volcanic fields. Analytical methods detailed in the text.

Table 3. ^{40}Ar-^{39}Ar ages of separated amphibole, biotite and plagioclase from lavas collected during dives along the Corsica margin.

Table 4.

Major element oxides (wt.%) and trace element (ppm) concentrations of selected samples of the offshore magmatism from the southwestern and northwestern Corsica margins, with references to onshore French Ligurian magmatism. Analytical methods detailed in the text. Fe_2O_3*: total iron as Fe_2O_3.

Table 5.

Wo-En-Fs compositions of selected primary clinopyroxenes (phenocrysts and microphenocrysts) from offshore mafic and intermediate lavas, after microprobe analyses. These data were performed using both the BRGM microprobe in Orléans and the Western microprobe in Brest; analytical conditions are detailed in Defant et al. (1991).

Appendix

Selected microprobe analyses of minerals compositions for the magmatic diversity of Corsica-Liguria lavas. Sheet 1 - clinopyroxenes; sheet 2 - feldspars; sheet 3 - biotites; sheet 4 - amphiboles and, sheet 5 - oxides.

Clinopyroxenes

Site 1: MA 74 DR05.

Site 3: Cyl 07-10; Cyl 07-11.

Site 7 : Cyl 20-02.

Site 9 : Cyl 22-03 ; Cyl 22-05 ; Cyl 22-7a

Site 10 : Marco Dr 52-03 ; Marco Dr 52-06; Marco Dr 52-07; Marco Dr 52-10.

Site 12 : Cyl 15-10.

Feldspars

Site 3: Cyl 07-10; Cyl 07-11, Cya 77-35 03.

Site 6: Cyl 02-01; Cyl 02-02.

Site 9 : Cyl 22-03 ; Cyl 22-05 ;Cyl 22-07a ; Cyl 22-08.

Site 12 : Cyl 15-10.

Biotites

Site 6: Cyl 02-01; Cyl 02-02.

Amphiboles

Site 6: Cyl 02-01

Oxides

Site 6: Cyl 02-02.

Offshore Oligo-Miocene volcanic fields within the Corsica-Liguria Basin: magmatic diversity and slab evolution in the western Mediterranean Sea

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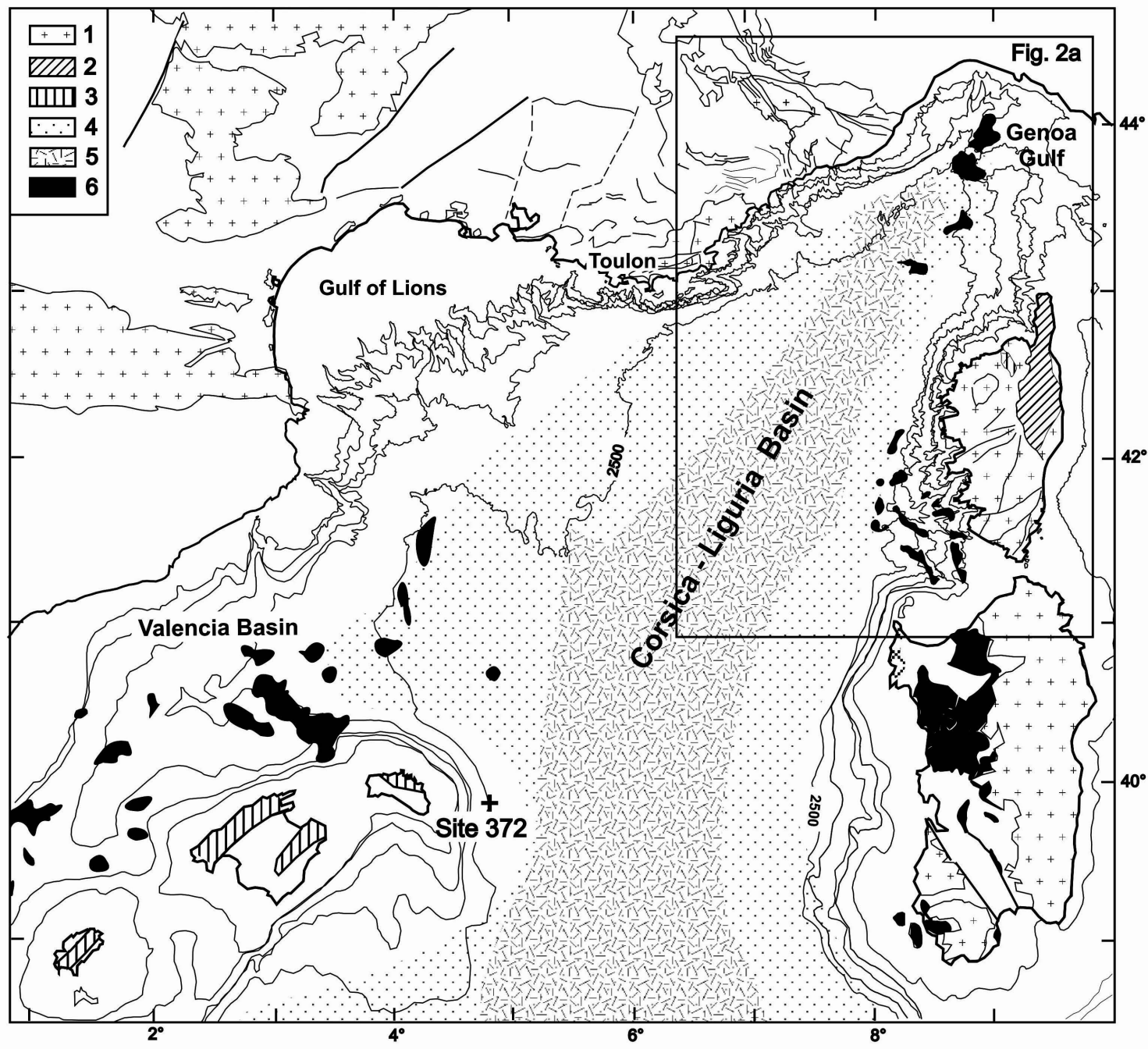
Highlights

- Presentation of an original collection of submarine rocks sampled by dredgings and in situ divings during 25 years within the Liguria-Corsica Basin.
- Geochemical diversity of lavas and K-Ar dating of whole rocks and ^{39}Ar-^{40}Ar of plagioclases and amphiboles between 30 and 6 Ma in several stages.
- West of Corsica, discovery of adakitic emissions K-Ar dated around 16 Ma.
- Transition from calc-alkaline, K-rich calc-alkaline and shoshonitic lavas to alkaline basalts in north Liguria Basin and in Toulonnais.
- Constraints on the kinematic and geodynamic evolution of the northwestern Mediterranean Sea (Liguria-Corsica Basin).


1
2
3
4
5
6
Fig. 2a
Genoa
Gulf
Toulon
Gulf of Lions
2500
Corsica - Liguria Basin
Valencia Basin
Site 372
2500
44°
42°
40°
2°
4°
6°
8°

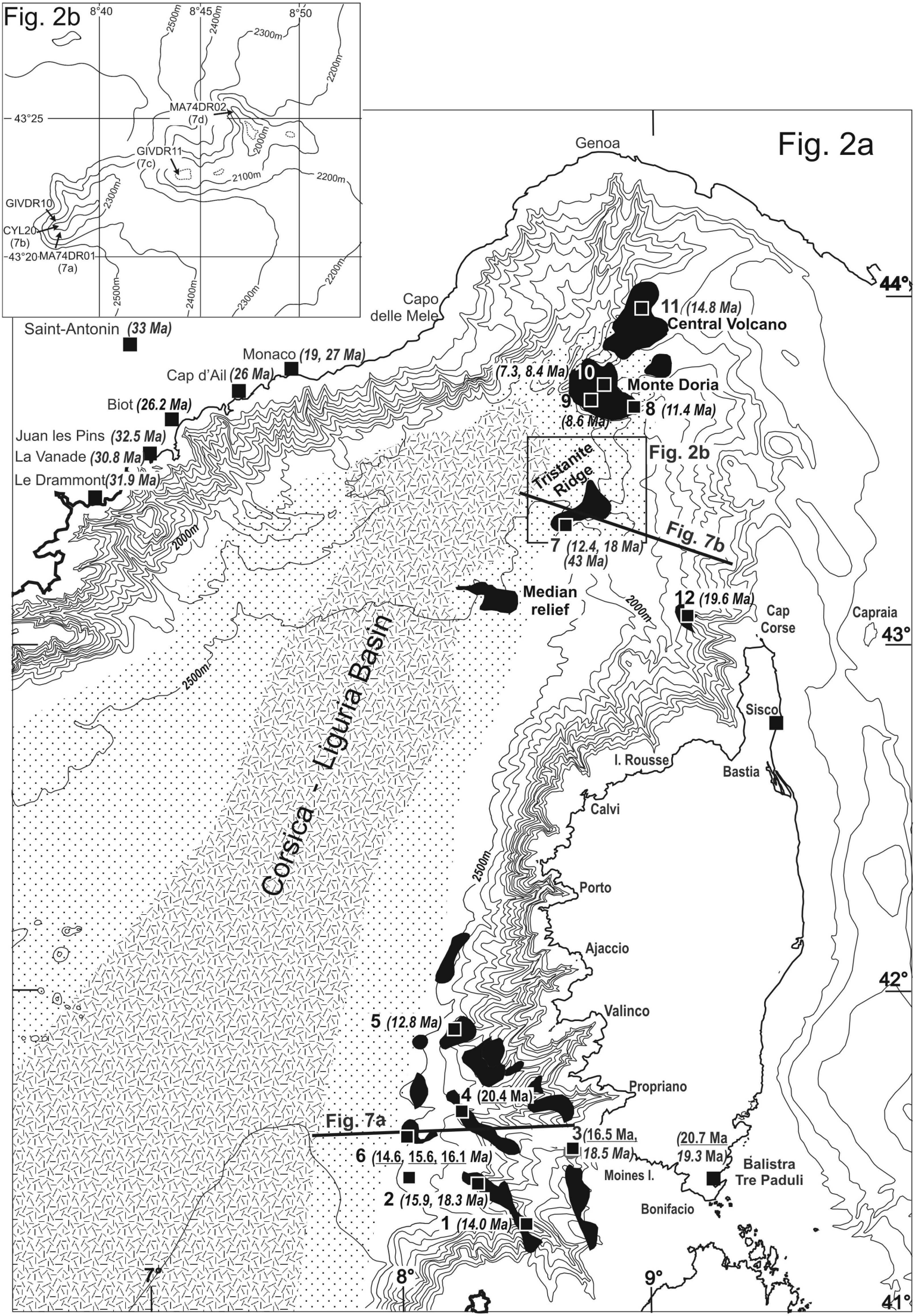
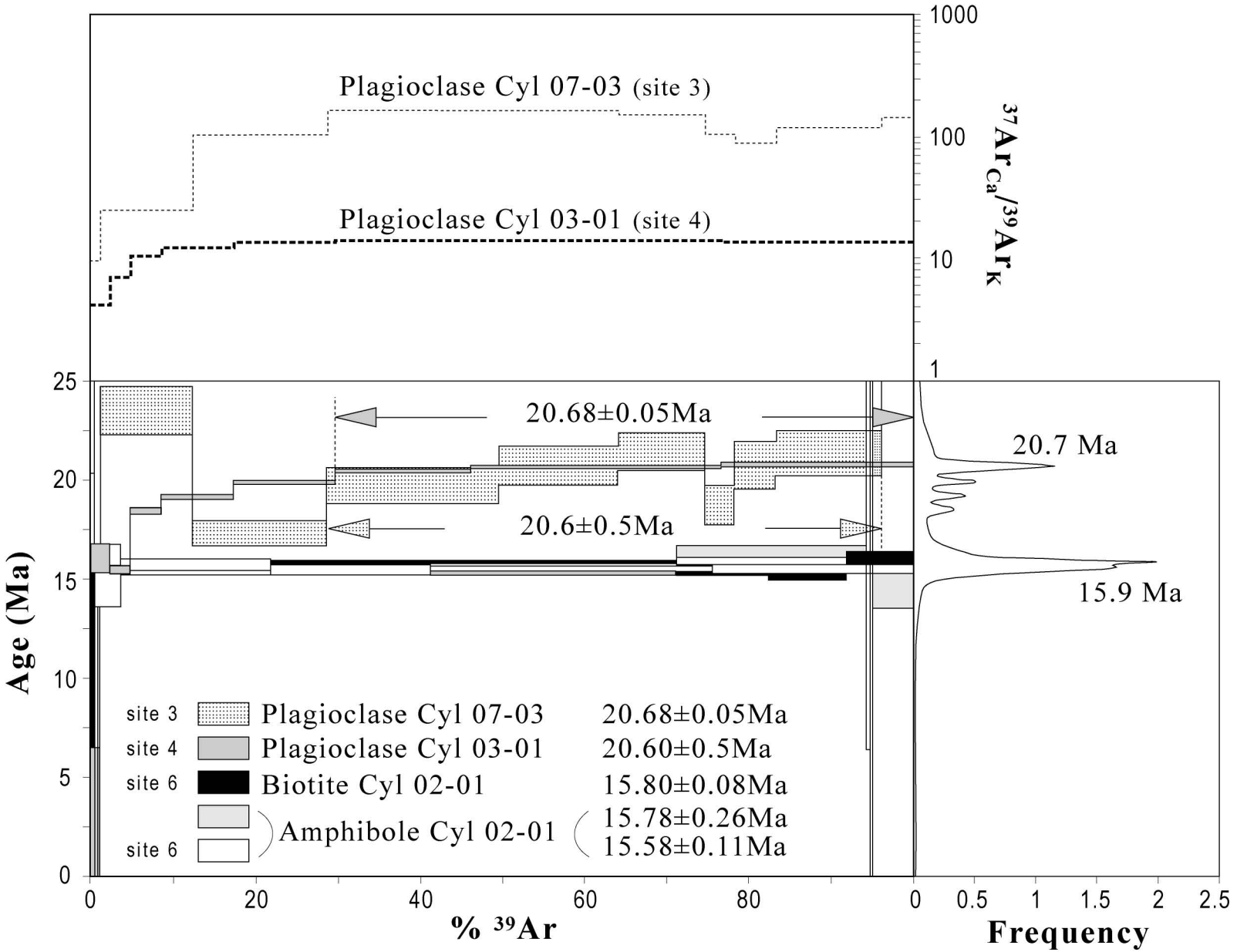
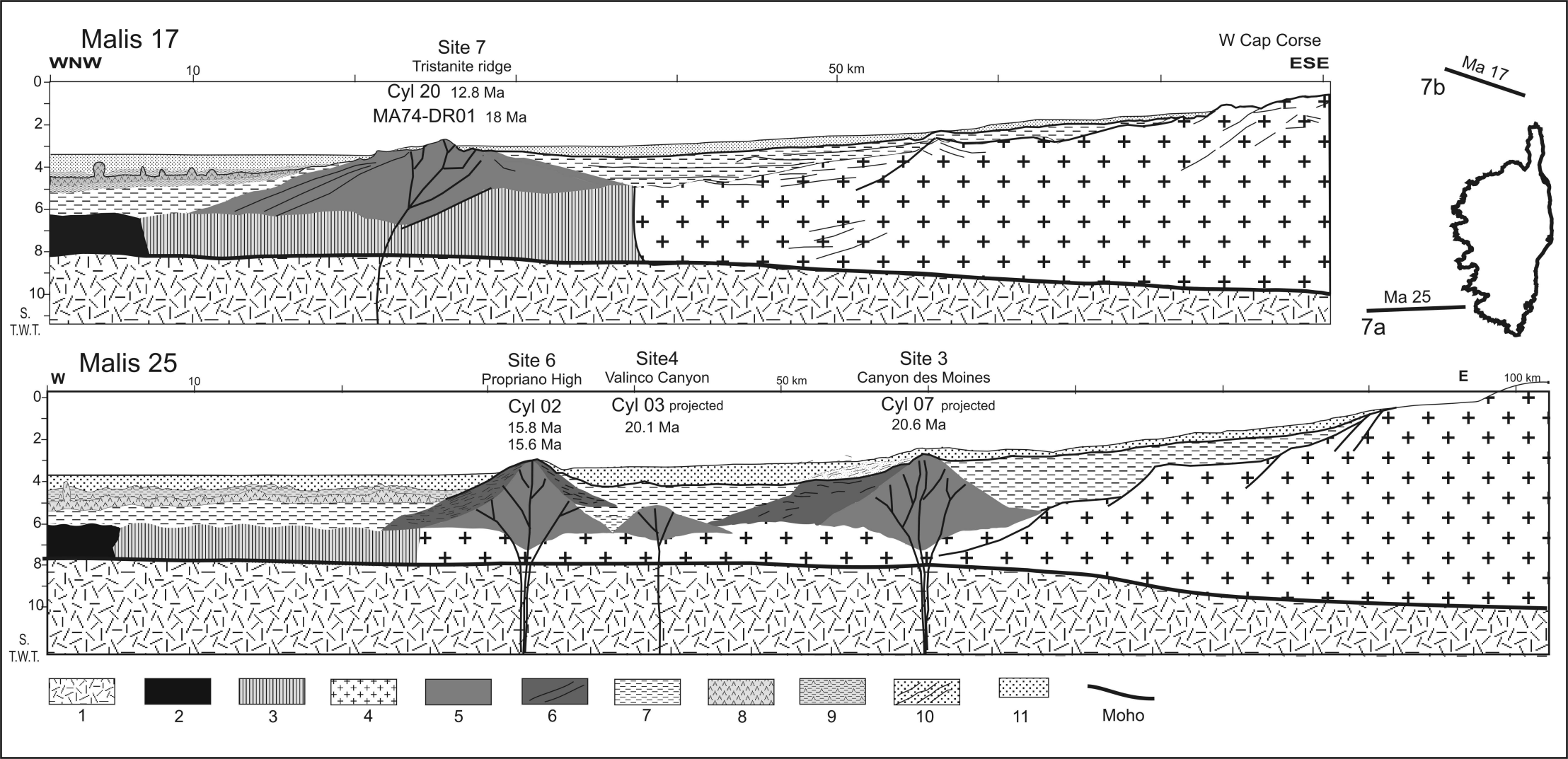
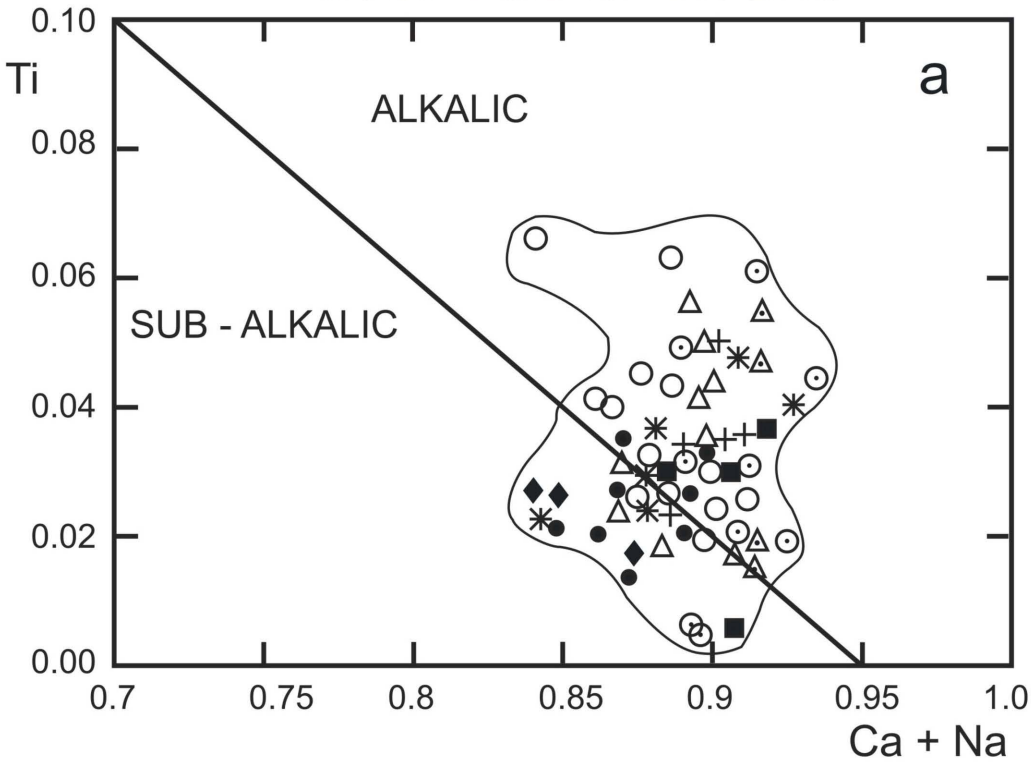


Fig. 2b
8°40
8°45
8°50
2500m
2400m
2300m
2200m
2100m
2000m
43°25
43°20
MA74DR02
(7d)
GIVDR11
(7c)
GIVDR10
CYL20
(7b)
MA74DR01
(7a)
Fig. 2a
Genoa
Capo
delle Mele
44°
11 (14.8 Ma)
Central Volcano
Saint-Antonin (33 Ma)
Monaco (19, 27 Ma)
Cap d'Ail (26 Ma)
(7.3, 8.4 Ma)
10
Monte Doria
9
8 (11.4 Ma)
(8.6 Ma)
Biot (26.2 Ma)
Juan les Pins (32.5 Ma)
La Vanade (30.8 Ma)
Le Drammont (31.9 Ma)
Fig. 2b
Tristanite
Ridge
Fig. 7b
7 (12.4, 18 Ma)
(43 Ma)
2000m
Median
relief
12 (19.6 Ma)
Cap
Corse
Capraia
43°
2500m
Corsica - Liguria Basin
Sisco
I. Rousse
Bastia
Calvi
Porto
Ajaccio
42°
Valinco
5 (12.8 Ma)
Propriano
4 (20.4 Ma)
Fig. 7a
3 (16.5 Ma,
18.5 Ma)
(20.7 Ma
19.3 Ma)
6 (14.6, 15.6, 16.1 Ma)
Moines I.
Balistra
Tre Paduli
2 (15.9, 18.3 Ma)
Bonifacio
1 (14.0 Ma)
7°
8°
9°
41°


Plagioclase Cyl 07-03 (site 3)
Plagioclase Cyl 03-01 (site 4)
1000
100
10
1
$^{37}Ar_{Ca}/^{39}Ar_K$
20.68±0.05Ma
20.6±0.5Ma
20.7 Ma
15.9 Ma
Age (Ma)
25
20
15
10
5
0
site 3 Plagioclase Cyl 07-03 20.68±0.05Ma
site 4 Plagioclase Cyl 03-01 20.60±0.5Ma
site 6 Biotite Cyl 02-01 15.80±0.08Ma
site 6 Amphibole Cyl 02-01 15.78±0.26Ma
15.58±0.11Ma
0
20
40
60
80
% ^{39}Ar
0
0.5
1
1.5
2
2.5
Frequency


Malis 17
WNW
Site 7
Tristanite ridge
W Cap Corse
ESE
10
50 km
Cyl 20 12.8 Ma
MA74-DR01 18 Ma
0
2
4
6
8
10
S.
T.W.T.
7b
Ma 17
Ma 25
7a
Malis 25
W
Site 6
Propriano High
Site4
Valinco Canyon
Site 3
Canyon des Moines
E
100 km
Cyl 02
15.8 Ma
15.6 Ma
Cyl 03 projected
20.1 Ma
Cyl 07 projected
20.6 Ma
1
2
3
4
5
6
7
8
9
10
11
Moho

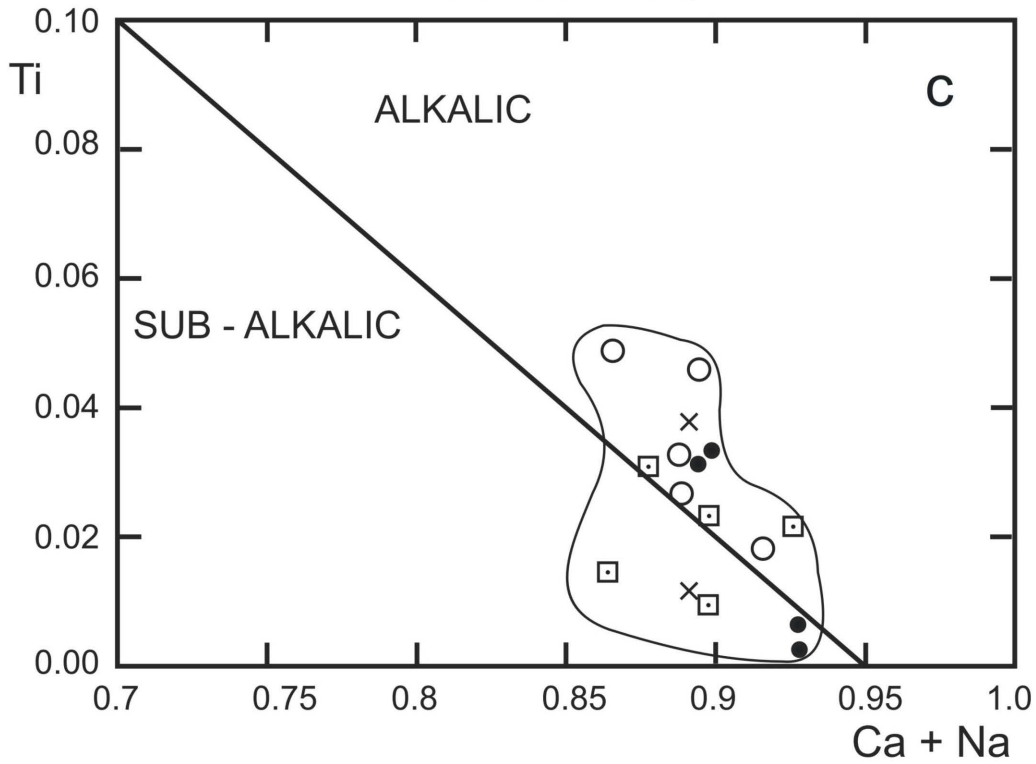
MONTE DORIA SEAMOUNTS



Site 9
- ○ CYL 22-03
- ⊙ CYL 22-04
- △ CYL 22-05
- \+ CYL 22-07
- ◬ GIV DR04

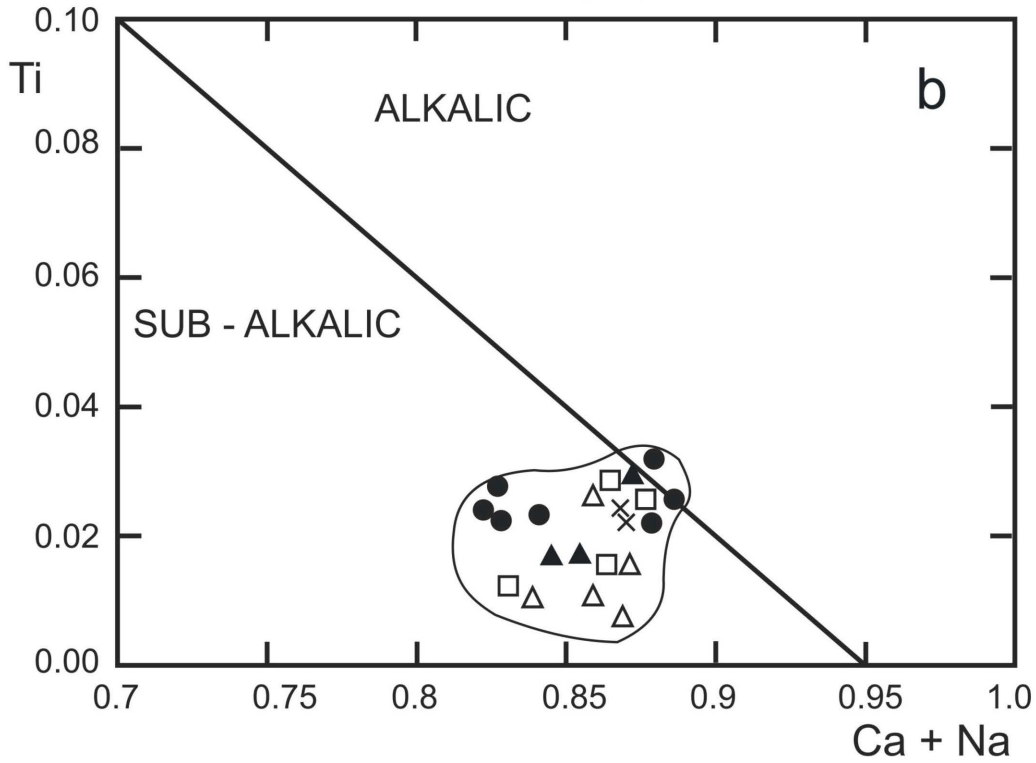
Site 10
- ✳ MARCO 52-03
- ● MARCO 52-06a
- ◆ MARCO 52-07
- ■ MARCO 52-10

TRISTANITE RIDGE



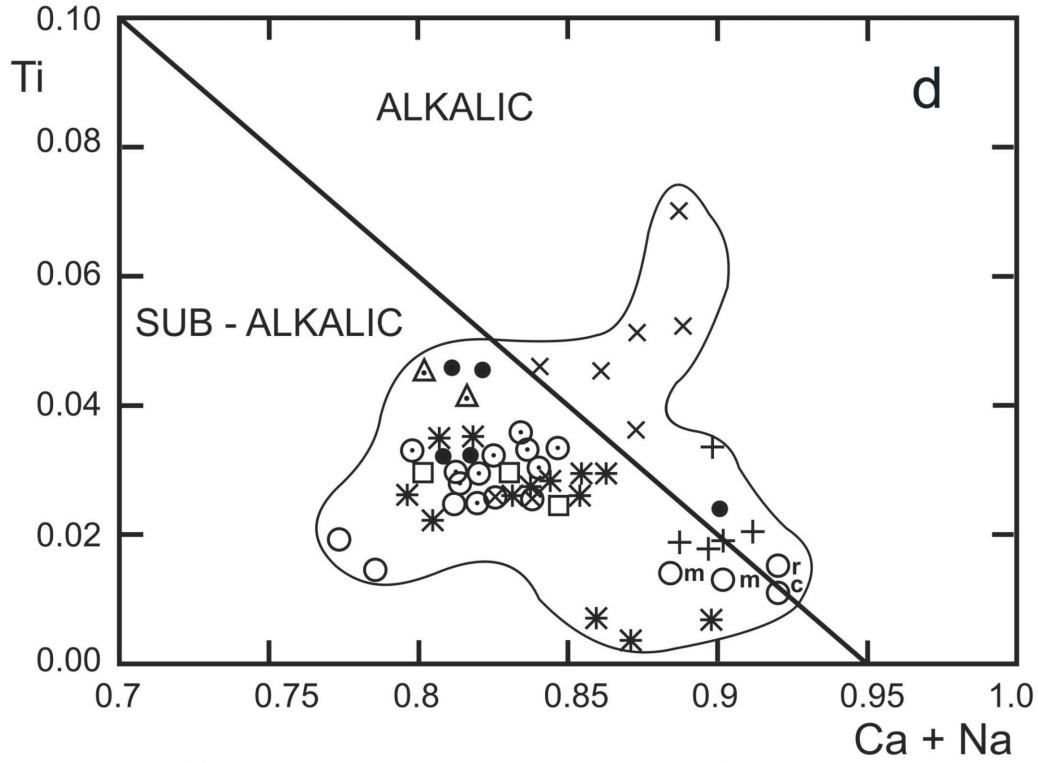
Site 7
- ● CYL 20-01a
- ⊡ CYL 20-01b
- × CYL 20-02
- ○ CYL 20-04

CAP CORSE



Site 12
- ● CYL 15-04
- △ CYL 15-06
- × CYL 15-08
- □ CYL 15-10a
- ▲ CYL 15-10b

SOUTHWEST CORSICA



Site 1
- \+ MA74DR05

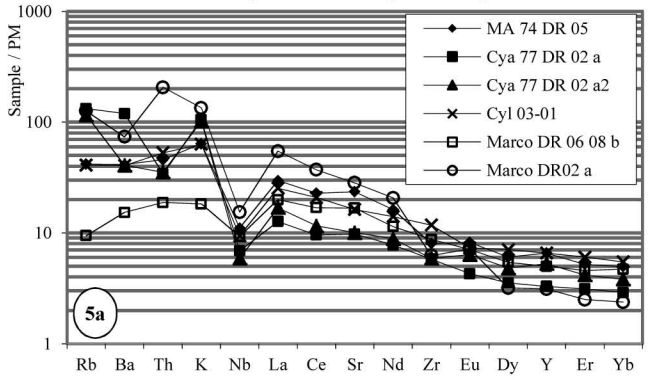
Site 3
- □ CYL07-01
- ○ CYL07-07
- ✳ CYL07-10
- ⊙ CYL07-11

rim ○ r
core ○ c
microlith ○ m

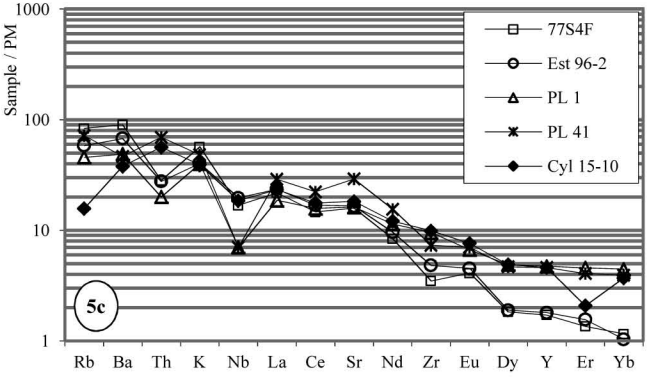
Site 4
- ● CYL03-01a
- ◬ CYL03-01

Site 6
- × CYL02-02
- ⊗ CYL02-01

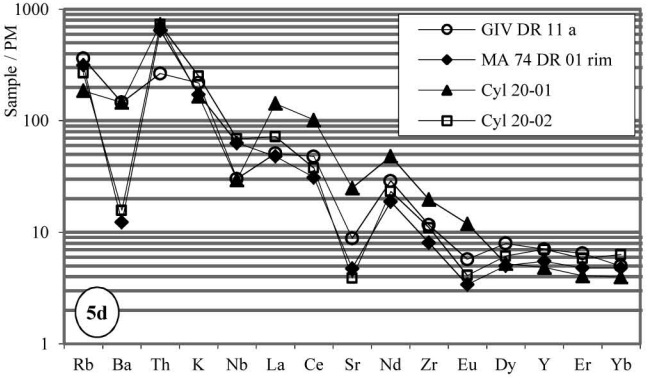
SW Corsica, Monte Paoli, Castelsardo and Valinco Canyons and Ajaccio and Propriano Highs



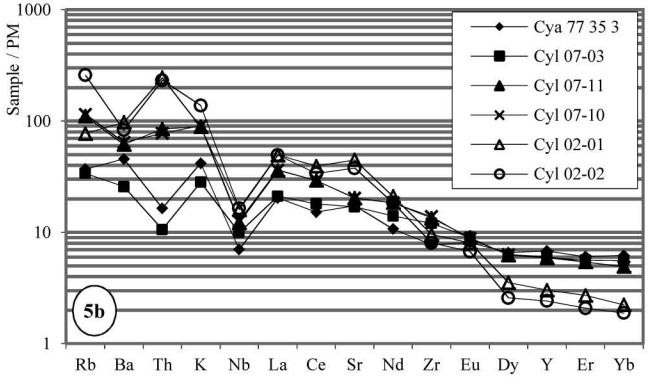
Cap Corse and onshore Ligurian magmatism



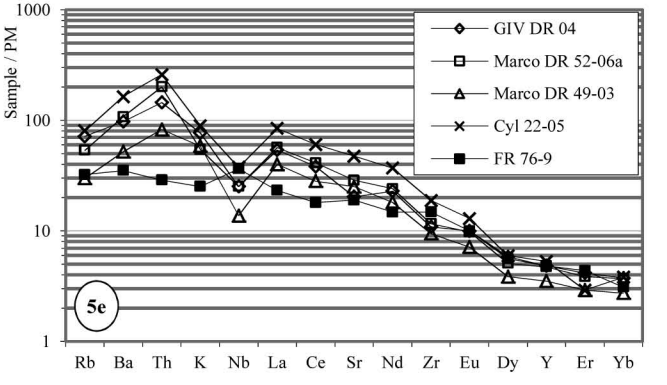
Tristanite Ridge

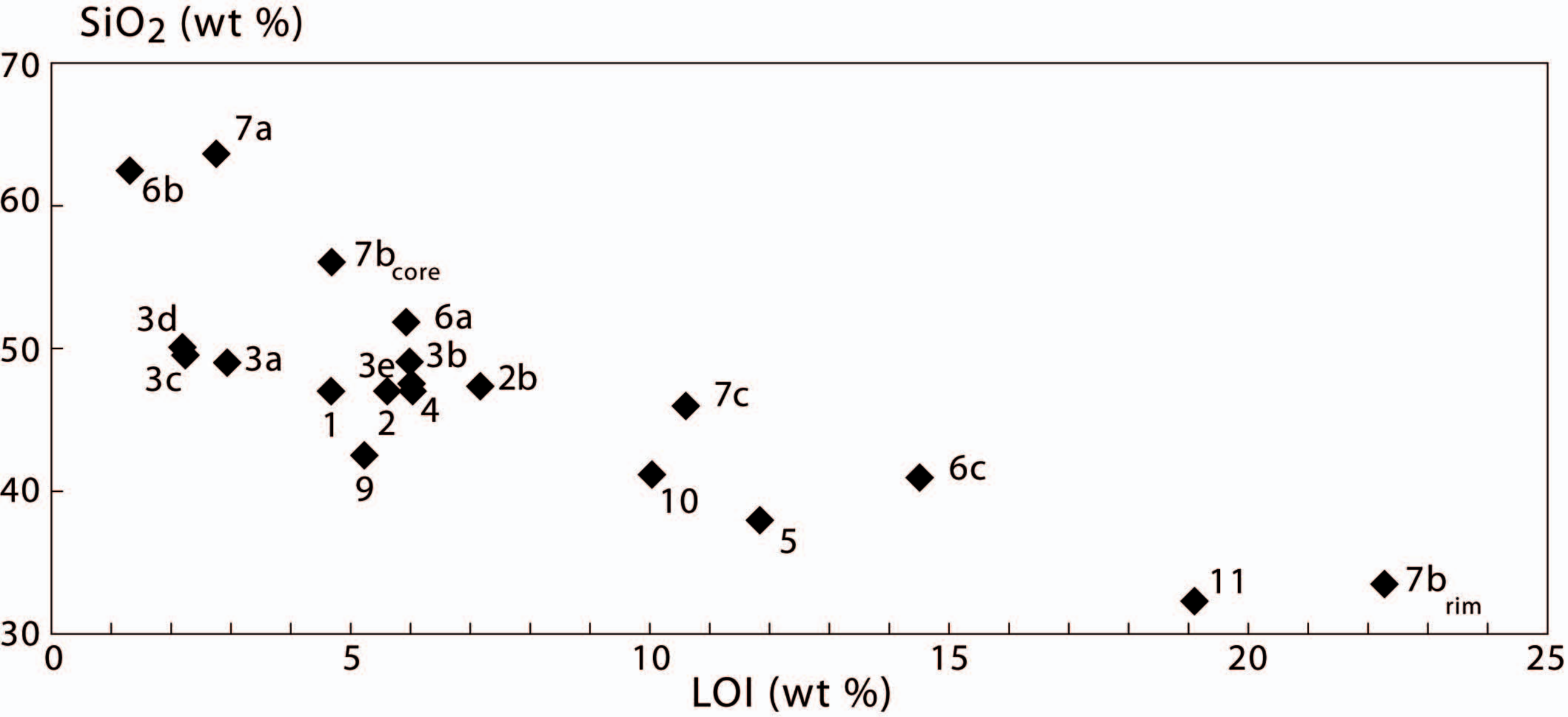


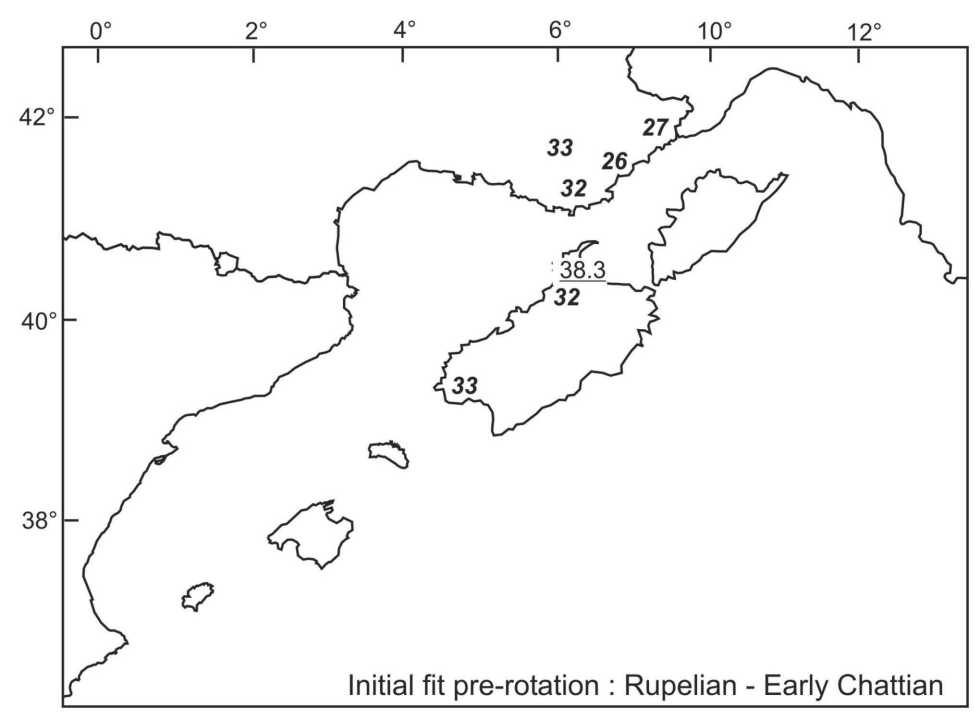
SW Corsica, Canyon des Moines and Propriano High

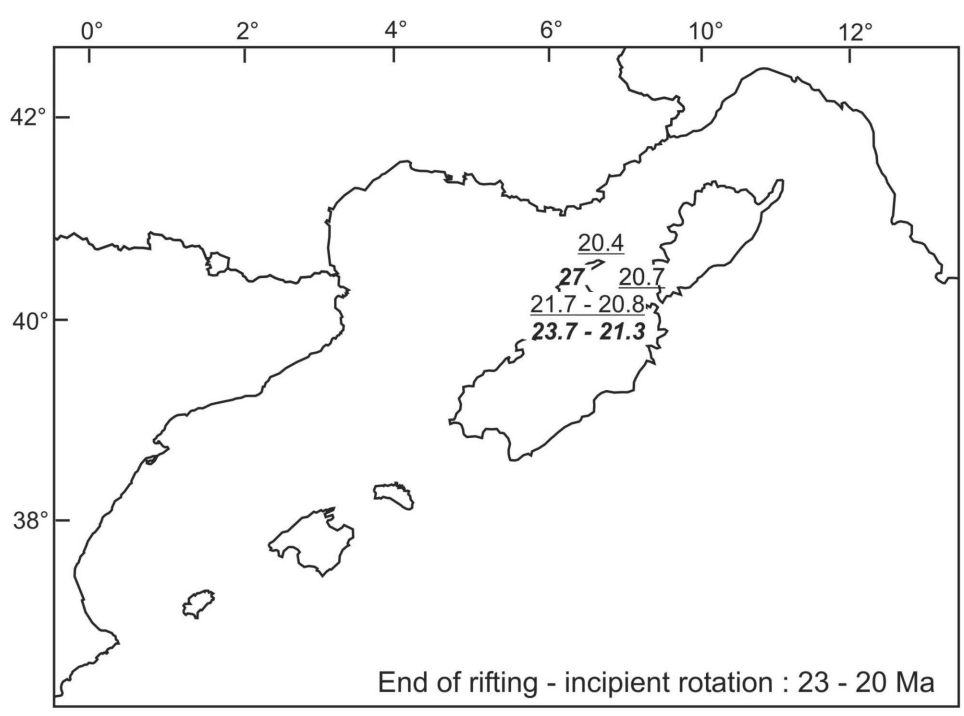


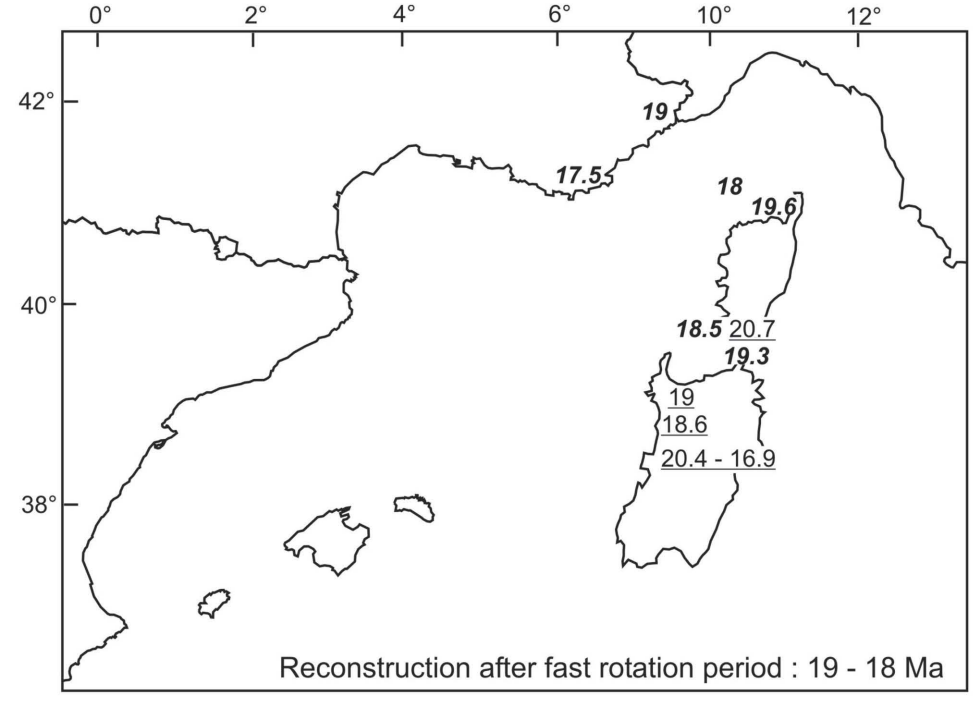
Doria seamounts complex, Genoa Gulf Central Volcano, and Toulonnais lavas

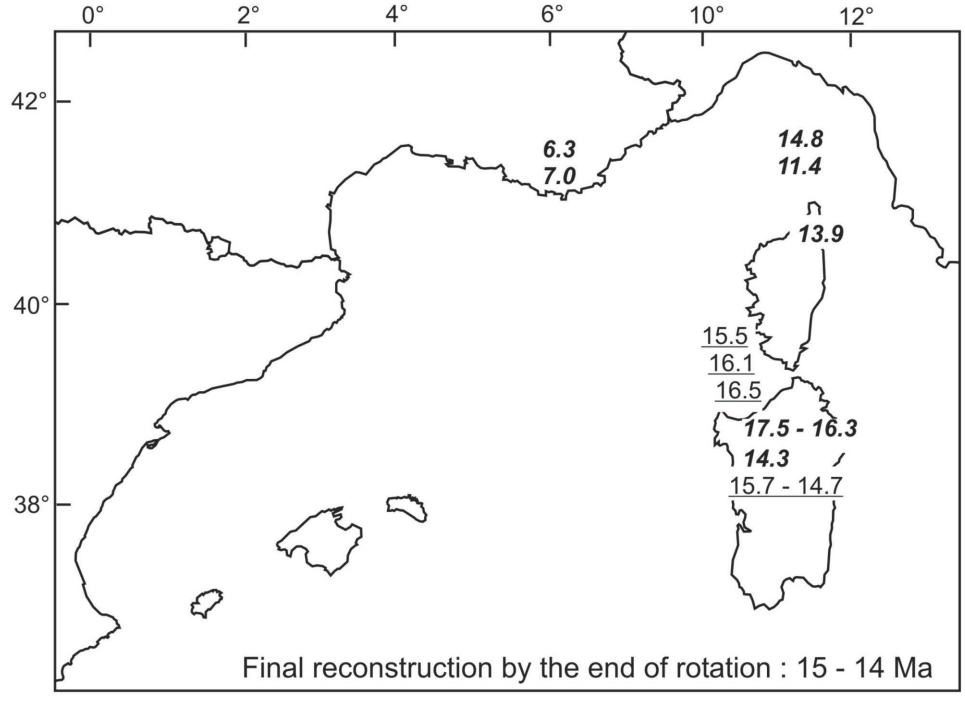



SiO2 (wt %)
70
60
50
40
30
0
5
10
15
20
25
LOI (wt %)
7a
6b
7b core
6a
3d
3a
3c
3e
3b
2b
7c
1
2
4
9
10
6c
5
11
7b rim


0°
2°
4°
6°
10°
12°
42°
40°
38°
27
33
26
32
38.3
32
33
Initial fit pre-rotation : Rupelian - Early Chattian


0°
2°
4°
6°
10°
12°
42°
40°
38°
20.4
27
20.7
21.7 - 20.8
23.7 - 21.3
End of rifting - incipient rotation : 23 - 20 Ma


0°
2°
4°
6°
10°
12°
42°
40°
38°
19
17.5
18
19.6
18.5
20.7
19.3
19
18.6
20.4 - 16.9
Reconstruction after fast rotation period : 19 - 18 Ma


0°
2°
4°
6°
10°
12°
42°
40°
38°
6.3
7.0
14.8
11.4
13.9
15.5
16.1
16.5
17.5 - 16.3
14.3
15.7 - 14.7
Final reconstruction by the end of rotation : 15 - 14 Ma

	Castelsardo	Monte Paoli			Canyon des Moines				Valinco	Ajaccio High			Propriano High	
	Site 1	Site 2		Site 3	Site 3	Site 3	Site 3	Site 3	Site 4	Site 5	Site 5	Site 6	Site 6	Site 6
	MA 74 DR 05	Cya DR 02a	Cya DR 02a2	Cyl 07-07	Cyl 07-03	Cyalig 77 35 3	Cyl 07-11 (a)	Cyl 07-10	Cyl 03-01	Marco DR 06 08	Marco DR 06 08 b	Marco DR 02a	Cyl 02-01	Cyl 02-02
(wt. %)														
SiO_2	47.00	47.00	47.30	47.00	47.50	49.00	49.50	50.00	49.00	38.50	41.00	41.00	51.80	62.40
TiO_2	1.03	1.06	1.05	1.14	1.24	0.92	1.27	1.28	1.09	0.90	0.94	0.49	0.53	0.45
Al_2O_3	18.55	18.00	18.40	19.8	22.00	24.85	18.60	18.60	22.10	18.10	18.20	18.45	20.20	18.10
Fe_2O_{3*}	11.55	12.75	11.15	8.6	7.90	4.50	10.33	9.74	6.77	8.9	3.73	3.85	4.25	2.75
MnO	0.06	0.31	0.11	0.07	0.12	0.18	0.11	0.13	0.05	0.17	0.05	0.05	0.13	0.05
MgO	2.65	5.30	5.08	5.42	1.54	0.79	2.98	2.96	1.20	9.35	9.90	8.68	3.75	1.75
CaO	9.35	3.30	3.00	7.25	9.45	12.35	8.40	8.40	8.35	9.30	3.70	4.50	5.73	4.20
Na_2O	2.79	2.15	2.50	3.10	3.20	3.13	3.20	3.25	2.95	1.95	3.40	3.36	4.46	3.70
K_2O	1.92	3.17	3.08	0.77	0.85	1.26	2.70	2.74	1.90	0.45	0.55	4.05	2.67	4.15
P_2O_5	0.57	0.18	0.28	0.2	0.26	0.23	0.35	0.36	0.26	0.26	0.22	0.20	0.19	0.15
LOI	4.7	5.64	7.2	6.06	6.04	2.97	2.29	2.23	6.01	11.85	9.89	14.54	5.96	1.36
Total	100.17	98.86	99.15	99.41	100.10	100.18	99.73	99.69	99.68	99.23	99.42	99.17	99.67	99.06
	MA 74 DR 05	Cya DR 02a	Cya DR 02a2	Cyl 07-07	Cyl 07-03	Cyalig 77 35 3	Cyl 07-11	Cyl 07-10	Cyl 03-01	Marco DR 06 08	Marco DR 06 08 b	Marco DR02a	Cyl 02-01	Cyl 02-02
(ppm)														
Rb	26.5	84	73.5	7.3	21.5	23.5	70	73	26	5.5	6	80	49	164
Ba	289	835	285	150	180	319	430	450	284	99	107	515	680	580
Th	3.9	2.9	3.0	0.9	0.9	1.4	7.2	6.6	4.5	1.8	1.6	17.5	20.8	19.7
Nb	7.9	4.9	4.2	5	7.1	5	8.7	9	6.7	6.3	6.6	11	11.4	11.7
La	20.4	8.7	11.6	13.1	14.5	14	24.8	25	17.4	15	13.7	37.5	34	34
Ce	40.5	17	20.5	28	32	27	52	52	37	31	30	66	70	60
Sr	497	206	212	280	358	365	430	428	343	358	354	596	945	795
Nd	22	10.5	12	16	19	14.5	25	25	19	16.5	15.5	28	28.5	25
Zr	90	65	66	100	135	87	150	155	132	97	98	70	107	90
Eu	1.38	0.72	1.07	1.39	1.51	1.36	1.51	1.47	1.23	1.20	1.19	1.21	1.35	1.13
Dy	4.45	2.6	3.55	5.1	4.6	4.85	4.6	4.65	5.2	4.15	4.0	2.35	2.6	1.9
Y	30	15	24	31.5	27	31	26.8	27.5	30	24.5	22.7	14.2	13.8	11
Er	2.5	1.5	2	3	2.7	2.9	2.6	2.6	2.9	2.3	2.2	1.2	1.3	1
Yb	2.45	1.43	1.88	2.75	2.75	3.06	2.43	2.40	2.70	2.43	2.32	1.17	1.1	0.93
Cr	40	26	44	5	11	5	39	37	7	14	15	13	13	11
Ni	16	26	92	7	7	4	23	23	12	32	16	36	34	16
Co	14.5	26	33	22	13	6	24	29	13	30	21	11	15	6
Sc	23.5	24	26	32	34	25	24	26	22	24	25	8.3	9.3	6
V	252	275	270	275	305	170	260	270	240	165	174	76	80	58

Analyses - for major elements: in Brest, UBO, except for (a) - Orléans, BRGM; and (b) - Clermont-Ferrand, University; and for trace elements: Brest, UBO.

	Tristanite Ridge				Doria SW flank	Seamounts	Centre	Genoa Gulf Volcano	Cap Corse	Onshore magmatism: Drammont		Tourettes	Villa Maure	Toulon
	Site 7	Site 7	Site 7	Site 7	Site 9	Site 9	Site 10	Site 11	Site 12	Ref	Ref	Ref	Ref	Ref
	Cyl 20-01	G IV DR 11a	MA 74 DR 01 core (b)	Cyl 20-02	GIV DR04	Cyl 22-05	Marco DR 52-06a	Marco DR 49-03	Cyl 15-10	77S4F	Est 96-2	PL1	Pl 41	FR 76-9
(wt. %)														
SiO_2	46.00	53.00	56.04	63.00	42.50	47.00	41.20	32.25	44.00	61.60	63.00	52.90	53.85	48.60
TiO_2	0.67	0.64	0.14	0.10	1.40	1.03	1.32	0.87	1.34	0.39	0.43	0.88	0.85	2.82
Al_2O_3	17.20	17.72	19.32	16.90	13.30	18.55	14.80	12.80	16.00	18.20	18.00	18.10	16.43	11.5
Fe_2O_{3*}	4.00	4.61	5.12	1.12	14.70	11.55	6.62	6.13	11.00	4.45	4.25	9.32	9.55	14.55
MnO	0.08	0.06	0.01	0.01	0.30	0.06	0.10	0.21	0.09	0.10	0.19	0.17	0.17	0.19
MgO	8.00	3.90	1.65	1.64	4.76	2.65	9.24	2.38	3.76	1.70	1.69	3.8	4.55	9.55
CaO	3.45	3.30	0.97	1.22	8.50	9.35	11.3	20.50	10.81	4.10	5.01	9.00	9.3	8
Na_2O	3.70	3.63	4.76	4.45	2.81	22.79	2.68	3.17	3.54	4.45	4.75	3.30	3.05	2.72
K_2O	5.00	6.58	7.17	7.55	2.31	1.92	1.64	1.76	1.18	1.71	1.21	1.20	1.45	0.76
P_2O_5	0.37	0.30	nd	0.01	0.70	0.57	0.47	0.59	0.67	0.17	0.19	0.22	0.25	0.3
LOI	10.62	5.57	4.72	2.81	5.25	4.70	10.05	19.11	7.42	2.95	1.49	1.20	0.96	0.09
Total	99.09	99.39	99.90	99.41	96.53	100.17	99.445	99.77	99.81	99.82	100.2	100.09	100.41	99.08

	Cyl 20-01	G IV DR 11a	MA 74 DR01 rim	Cyl 20-02	GIV DR04	Cyl 22-05	Marco DR 52-06a	Marco DR 49-03	Cyl 15-10	77S4F	Est 96-2	PL1	PL 41	FR 76-9
(ppm)														
Rb	118	2230	200	170	230	26.5	34	19	10	53	37	29	45.5	20.5
Ba	1020	1120	86	110	1120	289	750	363	265	630	472	342	325	246
Th	62	3.9	55	62	nd	3.9	17	7	4.8	2.4	2.35	1.7	5.9	2.45
Nb	21	21.5	45	49	21.5	7.9	18	9.8	13.2	12	14	5	5	34
La	98	35	33	49.5	35	20.4	39	27.5	16	15	16.2	12.8	19.9	16
Ce	180	85	55	67	85	40.5	73	50	31.3	26	30	28	39.5	32
Sr	525	186	100	82	186	497	605	530	385	335	350	342	615	400
Nd	65	39	25.5	31.5	39	22	32.5	24.5	16.4	11.4	13	15.5	21	20
Zr	220	130	90	123	130	90	130	106	111	39	54	107	82	166
Eu	2.00	0.96	0.57	0.69	0.96	1.38	1.64	1.2	1.28	0.69	0.76	1.12	1.18	1.68
Dy	3.85	5.85	3.7	4.5	5.85	4.45	3.75	2.85	3.6	1.35	1.4	3.6	3.45	4.15
Y	22	32	25	32	32	30	21.5	16	21	7.8	8.2	21.5	21	22
Er	1.95	3.10	2.30	2.80	3.10	2.50	1.85	1.40	1.00	0.65	0.75	2.20	1.95	2.1
Yb	1.96	2.45	2.36	3.10	2.45	2.45	1.82	1.35	1.83	0.57	0.51	2.20	1.94	1.53
Cr	54	91	2	10	172	40	125	72	203	4	5	12	40	375
Ni	50	77	183	25	172	16	81	45	121	6	2	8	14	220
Co	14	18	3	6	50	14.5	35	23	36.5	8	7	22	23	53
Sc	12	10.8	1.2	0.7	22.5	23.5	23	14.2	23.5	4.0	4.2	27.0	34	21

V	86	56	5	3	230	252	195	96	206	60	80	260	320	210	

	Temp. °C / Step n°	$^{40}Ar_{Atm.}$ (%)	$^{39}Ar_K$ (%)	$^{37}Ar_{Ca}/^{39}Ar_K$	^{40}Ar */$^{39}Ar_K$	Age (Ma)	±	error
Site 1	**Plagioclase Cyl 03-01** Bulk sample J=0,0604228							
Castelsardo Canyon	400	100	0	7.4	-	-	±	-
	500	100	0.02	7.4	-	-	±	-
	600	80.8	0.04	$2x10^{-3}$	23.04	47.81	±	4.68
	700	65.1	2.29	4.2	7.69	16.11	±	0.74
	800	32.4	2.48	7.1	7.42	15.54	±	0.21
	900	23.2	3.73	10.5	8.86	18.53	±	0.17
	1000	18.2	8.71	12.3	9.19	19.22	±	0.13
	1100	9.4	12.31	13.6	9.54	19.95	±	0.1
	1200	6.14	16.37	13.9	9.81	20.51	±	0.09
	1300	7.86	30.69	13.9	9.89	20.68	±	0.09
	1400	13.7	8.99	13.4	9.94	20.79	±	0.14
	1500	19.7	14.36	13.4	9.95	20.8	±	0.12
					Integrated age	20.15	±	0.05
Site 3	**Plagioclase Cyl 07-03** Bulk sample J = 0.0603868							
Canyon des Moines	400	100	0	$3x10^{-2}$	-	-	±	-
	500	99.3	1.18	9.6	0.99	2.08	±	4.5
	600	88.1	11.14	25.3	11.29	23.57	±	1.22
	700	64.1	16.28	106.2	8.31	17.38	±	0.65
	800	51.1	20.96	165.9	9.45	19.75	±	0.92
	900	52.5	14.53	166.5	9.94	20.77	±	1
	1000	61.5	10.6	152.7	10.27	21.45	±	0.98
	1100	78.2	3.59	105.9	8.97	18.76	±	1.04
	1200	83.7	5.03	88.8	9.93	20.75	±	1.22
	1400	80.2	12.78	120.2	10.23	21.37	±	1.15
	1550	78.4	3.91	145.6	12.73	26.56	±	1.65
					Integrated age	20.4	±	0.37
Site 6	**Cyl 02-01 Biotite** Single grain J=0,0602389							
Propriano High	1	91.3	0	127	-	-	±	-
	2	99.1	0.08	-	1.24	2.61	±	28.46
	3	74	0.33	-	5.65	11.81	±	9.06
	4	29.9	3.04	-	7.67	16.01	±	0.54
	5	17.3	5.73	-	7.57	15.81	±	0.27
	6	11	13.49	-	7.61	15.88	±	0.14
	7	6.9	12.11	$1x10^{-3}$	7.59	15.85	±	0.16
	8	5.2	36.63	1.1x10-2	7.62	15.91	±	0.07
	9	7.3	11.05	3.4x10-2	7.43	15.5	±	0.3
	10	8.5	9.43	8.9x10-2	7.34	15.33	±	0.38
	Fuse	3.5	8.13	8.3x10-2	7.65	15.97	±	0.45
					Integrated age	15.8	±	0.09
	Cyl 02-01 Amphibole Single grain J = 0.0603150							
	1	98.9	0.16	7.4x10-1	3.44	7.2	±	74.09
	2	164.3	0.24	6.2x10-1	-	-	±	-
	3	76	0.13	8.9x10-1	1.74	3.66	±	70.99
	4	193.5	0.38	7.6	-	-	±	-
	5	6.4	70.28	7.2	7.46	15.59	±	0.31
	6	0	23.02	7	7.85	16.41	±	0.31
	7	16.9	0.52	16.1	9.03	18.86	±	12.41
	8	37.2	0.33	20.4	8.19	17.11	±	18.16
	Fuse	17.3	4.94	15.7	7.17	14.99	±	1.49
					Integrated age	15.51	±	0.31
	Cyl 02-01 Amphibole Single grain J = 0.0603150							
	1	86.9	0.46	$1x10^{-3}$	14.14	29.44	±	9.04
	2	21.4	3.18	-	7.28	15.23	±	1.58
	3	20.4	18.14	4.7	7.55	15.79	±	0.3
	4	14.2	19.39	5.8	7.42	15.52	±	0.25
	5	7.3	34.45	5.9	7.43	15.54	±	0.13
	Fuse	6.2	24.38	4.8	7.43	15.52	±	0.22
					Integrated age	15.63	±	0.12

		Depth of sampling	Sample	Analysed fraction	Analytical reference	Age Ma	±	error at ±1 σ	K_2O wt.%	$^{40}Ar_R$ %	$^{40}Ar_R$ $10^{-7}cm^3/g$	^{36}Ar $10^{-9}cm^3/g$	Mass fused (g)
	SW CORSICA												
Site 1	Castelsardo Canyon	-1785 m	MA 74DR 05	WR	B 4184	14.00	±	0.40	1.91	41.2	8.68	4.20	0.5049
				WR	B 7144	13.70	±	0.56	2.00	24.3	8.89	2.56	0.2732
Site 2	Monte Paoli	-1980 m	Cya 77DR02-a2	WR	B 4487	15.90	±	0.40	3.07	48	15.82	5.80	0.7056
		-1980 m	Cya 77DR02-a	WR	B 4486	18.00	±	0.50	3.28	36.4	19.13	0.11	0.7060
				"	B 4492	18.50	±	0.50	"	39.6	19.68	0.10	0.7065
Site 3	Canyon des Moines	-1137 m	Cyl 07-07	WR	B 5029	10.98	±	0.80	0.79	14.6	2.80	5.54	0.5070
				"	B 5024	12.38	±	1.10	"	13	3.16	7.17	0.4033
		- 983 m	Cyl 07-10	WR	B 5023	19.35	±	0.46	2.58	91.5	16.18	0.51	0.6535
				"	B 5030	19.07	±	0.44	"	92.8	15.95	0.42	0.6510
		- 980 m	Cyl 07-11	WR	B 5022	19.16	±	0.45	2.39	90.3	14.84	0.54	0.6506
Site 5	Ajaccio high	-1700 m	Marco DR06-08	WR	B 7143	12.83	±	1.83	0.47	6.7	1.95	2.61	0.2852
Site 6	Propriano high	-2681 m	Cyl 02-02	WR	B 5021	14.52	±	0.34	4.33	89.3	20.34	0.83	0.6021
					B 5025	14.68	±	0.34	"	89.1	20.58	0.85	0.6640
		-2250 m	Marco DR02	WR	B 4183	11.90	±	0.30	3.89	75.2	14.96	1.67	0.4176
	NW CORSICA												
Site 7a	Tristanite Ridge	-2470 m	MA 74DR 01 rim	WR	B 4124	15.70	±	0.40	4.59	53.9	23.33	6.74	0.3535
Site 7b	Tristanite Ridge	-2531 m	Cyl 20-01	WR	B 4599	12.80	±	0.30	5.14	77.9	21.40	2.05	0.7013
		-2440 m	Cyl 20-02	WR	B 4598	12.40	±	0.30	8.40	81.6	33.72	2.57	0.6021
Site 7c	Tristanite Ridge	-2280 m	GIV DR 11a	WR	B 5286	42.77	±	2.30	6.20	84.6	86.53	3.22	0.6038
				"	B 7134	43.26	±	2.34	"	76.9	87.52	1.81	0.2036
Site 9	Monte Doria, SW flank	-1574 m	Cyl 22-05	WR	B 7290	8.57	±	0.31	2.74	28.6	7.58	3.20	0.2604
Site 10	Monte Doria, centre	- 904 m	Marco DR52-06 a	WR	B 7145	7.35	±	0.32	1.79	22.5	4.25	1.29	0.2604
			Marco DR52-06 b	WR	B4240	8.37	±	0.33	1.63	43.7	4.41	1.35	0.7020
Site 11	Genoa Gulf Central Volcano	- 470 m	Marco DR49-03	WR	B 7138	14.83	±	1.40	1.18	24.2	5.66	1.13	0.1886
Site 12	Cap Corse	-1290 m	Cyl 15-10	WR	B 7142	19.59	±	1.32	1.57	14.0	9.97	5.39	0.2601

		Depth of sampling	Sample	Petrographical and geochemical type	Dated fraction method / technics	Age Ma	±	error 1 sigma	K_2O wt. % (AAS)	Geochemical analyses Analytical reference	LOI wt%	SiO2 wt%	K_2O wt%
	SW CORSICA												
Site 1	Castelsardo Canyon	- 1785 m	MA 74 DR 05a	Basaltic flow	WR K-Ar age	14.0	±	0.40	1.91	JC 12571	4.70	47.0	1.92
			MA 74 DR 05b			13.7	±	0.90	2.00				
		- 1859 m	Cyl 01-03	Basaltic flow									
Site 2	Monte Paoli	- 1980 m	Cya 77 DR02-a2	HK basaltic andesite	WR K-Ar age	15.90	±	0.40	3.07	AC 13996	7.20	47.3	3.08
		- 1980 m	Cya 77 DR02-a		WR K-Ar age	18.25	±	0.50	3.28	AC 13995	5.64	47.0	3.17
Site 3	Canyon des Moines	- 983 m	Cyl 07-10	Doleritic diabase	WR K-Ar age	19.21	±	0.46	2.58	AC 14657	2.23	50.0	2.74
		- 980 m	Cyl 07-11	Doleritic diabase	WR K-Ar age	19.36	±	0.45	2.39	AC 14657	2.29	49.5	2.70
		- 1104 m	Cyl 07-03	Porphyritic basalt	Plag. ^{40}Ar-^{39}Ar plateau age	20.68	±	0.05		AC 14655	6.04	47.5	0.85
		- 1137 m	Cyl 07-07	Porphyritic basalt	WR K-Ar age	11.70	±	1.10	0.79	AC 14656	6.06	47.0	0.77
		- 1177 m	Cyl 07-01										
		- 1682 m	Cya 77-35 03	Jointed basaltic flow	Plag. ^{40}Ar-^{39}Ar plateau age	16.50	±	0.50					
					WR K-Ar age (a)	18.50	±	1.00	1.25				
Site 4	Valinco Canyon	- 2383 m	Cyl 03-01	Basaltic andesite	Plag. ^{40}Ar-^{39}Ar plateau age (seeTable 3)	20.6	±	0.50		AC 14654	6.01	49.0	1.90
Site 5	Ajaccio High	- 1700 m	Marco DR06-08	Basalt	WR K-Ar age	12.83	±	1.83	0.46	AC 12572	11.85	38.0	0.45
Site 6	Propriano High	- 1020 m	Cyl 06-08	Andesite									
		- 2000 m	Marco DR02-1a	K-rich basaltic andesite	Plag. ^{40}Ar-^{39}Ar plateau age	16.10	±	0.40					
		- 2250 m	Marco DR02	K-rich basaltic andesite	WR	11.90	±	0.30	3.89	AC 12569	14.54	41.0	4.05
		- 2681 m	Cyl 02-02	Andesite (adakite)	WR K-Ar age	14.60	±	0.34	4.33	AC 14653	1.36	62.4	4.15
		- 2690 m	Cyl 02-01	Basaltic andesite (adakitic)	Biot. ^{40}Ar-^{39}Ar plateau age	15.80	±	0.08		AC 14652	5.96	51.8	2.67
					Amp. ^{40}Ar-^{39}Ar plateau age (seeTable 3)	15.51 15.63	± ±	0.31 0.12					

Foot notes

Age results in normal characters correspond to lavas having a loss on ignition between 4 and 6 wt.%. They are to be considered with caution.

Underlned age results remain ambiguous as linked to a loss on ignition, upper than 6%. These ages have been possibly rejuvenated.

		Depth of sampling	Sample	Petrographical and geochemical type	Dated fraction method / technics	Age Ma	±	error 1 sigma	K_2O wt. % (AAS)	Geochemical analyses Analytical reference	LOI wt%	SiO_2 wt%	K_2O wt%
	NW CORSICA												
Site 7a	Tristanite Ridge	- 2470 m	MA 74 DR 01 rim	White welded ignimbritic tuf	WR K-Ar age	15.70	±	0.40	4.59	JC 12568	22.29	33.5	5.18
		- 2470 m	MA 74 DR 01 core	" "	WR K-Ar age	18.00	±	0.50	7.40	Cantagrel	4.72	56.04	7.17
Site 7b	Tristanite Ridge	- 2440 m	Cyl 20-02	White welded ignimbritic tuf	WR K-Ar age	12.40	±	0.30	8.40	JC 13998	2.81	63.6	7.55
		- 2531 m	Cyl 20-01	Andesite	WR K-Ar age	12.80	±	0.30	5.14	JC 13997	10.62	46.0	5.00
Site 7c	Tristanite Ridge	- 2285 m	Cyl 20-04	Andesite, top of the massif									
		- 2280 m	G IV DR 11a	Pillowed andesite	WR K-Ar age	43.00	±	2.34	6.20	JC 12576	5.57	53.0	6.58
Site 8	Monte Doria, eastern flank	- 1780 m	MFCB	Shoshonitic basalt flow (d)	WR and biot. K-Ar age (d)	11.40	±	0.70	3.3				
Site 9	Monte Doria, southwestern flank	- 780 m	F 81	Olivine basalt									
		- 1438 m	Cyl 22-07	Porphyritic basalt									
		- 1574 m	Cyl 22-05	Vesicular olivine basalt	WR K-Ar age	8.57	±	0.31	2.74	CL 2010	5.40	44.00	1.18
		- 1588 m	Cyl 22-04	Vesicular olivine basalt									
		- 1627 m	Cyl 22-03	Porphyritic basalt									
		- 2400 m	Cyl 21-04	Microlithic basalt									
		- 2450 m	Cyl 21-02	Vesicular olivine basalt									
		- 2490 m	GIV DR 04	Olivine basalt						JC 12570	5.25	42.50	2.31
Site 10	Monte Doria, centre	- 904 m	Marco DR52-06 b	Vesicular basalt	WR K-Ar age	7.30	±	0.70	1.79				
			Marco DR52-06 a	Basalt	WR K-Ar age	8.37	±	0.33	1.63	JC 12575	10.05	41.2	1.64
		- 1000 m	Marco DR52-03	Basalt									
Site 11	Genoa Gulf, Central Volcano	- 470 m	Marco DR49-03	Olivine basalt	WR K-Ar age	14.80	±	1.40	1.18	JC 12574	19.11	32.25	1.76
Site 12	Cap Corse	- 1290 m	Cyl 15-10	Microlithic basalt	WR K-Ar age	19.60	±	1.52	1.57	CL 2010	7.42	44.00	1.18
		- 1330 m	Cyl 15-08										
		- 1450 m	Cyl 15-06a										
		- 1495 m	Cyl 15-04a										

Ages from literature and references below

a- Bellon et al., 1984 b- Rossi et al., 1998 c- Cantagrel in Réhault, 1984 d- Fanucci et al., 1993

		Sample	WO	EN	FS	
	SW CORSICA					
Site 1	Castelsardo Canyon	MA74 DR 05	45.8 / 49.4	41.9 / 45.5	5.9 / 8.6	
Site 3	Canyon des Moines	Cyl 07-10	41.8 / 46.2	41.4 / 50	6 / 14.6	
		Cyl 07-11	41.1 / 44.9	41 / 42.6	12.4 / 14.9	
		Cya 77-35	38.9 / 41.4	43.6	15.3 / 17.3	
Site 4	Valinco Canyon	Cyl 03-01	42.5 / 43.2	36.7 / 38.2	18.6 / 20.7	
	NW CORSICA					
Site 7	Tristanite Ridge	Cyl 20-01	47.2 / 45.5	41.1 / 32.8	11.7 / 11	
		Cyl 20-02	46.1 / 48.6	47.2 / 51	3.0 / 5.8	
		Cyl 20-04	46.9 C / 47.8 R	46.8 C / 45.3 R	6.2 C / 6.9 R	Macrophenocrysts
Site 9	Monte Doria, SW flank	F 81	57.3	5	37.6	
		Cyl 22-05	47.1 / 49.6	44.4 / 47.1	5.8 / 7.1	
		Cyl 22-04	46.7	40.9	12.4	
		Cyl 22-03	47.9 C / 48.9 R	45.9 C / 46.8 R	6.1 C / 4.2 R	Phenocrysts
		"	48.2 / 48.8	43.7 / 44.8	6.4 / 8.1	Microphenocrysts
		G IV DR 04	45.3 / 47.6	41.7 / 43.7	10.6 / 11	
Site 10	Monte Doria, centre	Marco DR 52-03	46.6	47	6.4	Phenocryst
		"	44 / 51	45 / 48	3.8 / 6.4	Microphenocrysts
		Marco DR 52-06	44.7 / 47.6	45.2 / 47.7	7.2 / 7.6	Phenocrysts
		"	47 /47.7	46 / 46.8	6.1	Macrophenocrysts
		Marco DR 52-07	42 / 45	43.8 / 46.4	10.4 / 13.1	
Site 12	Cap Corse	Cyl 15-10	43.7 / 46.5	46.5 / 48.9	6.3 / 7.3	

Abbreviations

"C" core and "R" rim of macrophenocrysts and phenocrysts
WO - wollastonite, EN - enstatite, FS - ferrosilite

Feldspars

Site 1: Castelsardo Canyon

Site 3: Canyon des

Sample	MA74 Dr05	Ma74DR05	Ma74DR05	Ma74DR05	Ma74DR05	Cyl 07-10	Cyl 07-10
Shape	lath	microlith	lath	macrophenocryst		autom phen	
				core	rim	rim	core
SiO_2	51,19	51,24	46,31	44,57	45,81	50,89	49,84
TiO_2	0,06	0,05	0,03	0,00	0,01	0,04	0,05
Al_2O_3	29,51	29,76	33,40	34,43	33,91	29,96	30,53
Fe_2O_3	0,79	0,92	0,76	0,58	0,71	0,90	0,74
MgO	0,08	0,09	0,07	0,09	0,06	0,10	0,06
CaO	13,25	13,52	17,59	18,60	17,90	13,89	14,47
Na_2O	3,46	3,60	1,62	0,92	1,21	3,45	3,13
K_2O	0,36	0,37	0,11	0,01	0,06	0,39	0,45
Total	98,70	99,55	99,90	99,20	99,67	99,60	99,27
Si	2,36	2,35	2,14	2,08	2,12	2,33	2,30
Al	1,60	1,61	1,82	1,89	1,85	1,62	1,66
Fe3	0,03	0,03	0,03	0,02	0,03	0,03	0,03
Ti	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Mg	0,01	0,01	0,01	0,01	0,00	0,01	0,00
Na	0,31	0,32	0,15	0,08	0,11	0,31	0,28
Ca	0,66	0,66	0,87	0,93	0,89	0,68	0,72
K	0,02	0,02	0,01	0,00	0,00	0,02	0,03
->	4,99	5,00	5,01	5,01	5,00	5,00	5,01
OR	0,02	0,02	0,01	0,00	0,00	0,02	0,03
AB	0,31	0,32	0,14	0,08	0,11	0,30	0,27
AN	0,67	0,66	0,85	0,92	0,89	0,68	0,70

Moines

Site 3: Canyon des Moines

Cyl 07-10 macro phenocryst interm	Cyl 07-10 phenocryst rim	Cyl 07-10 microlith	Cyl 07-10 microlith	Cyl 07-10 microlith	Cyl 07-10 phenocryst core	Cyl 07-11 macro phenocryst core	Cyl 07-11 phenocryst rim	Cyl 07-11 phenoc core
51,26	50,74	64,70	53,13	50,16	52,58	51,64	58,69	52,91
0,05	0,06	0,19	0,10	0,06	0,05	0,04	0,08	0,04
28,84	29,19	19,22	28,78	30,18	28,58	29,28	23,14	29,01
0,68	0,97	0,30	1,12	0,76	0,80	0,68	0,39	0,73
0,11	0,14	0,02	0,13	0,14	0,11	0,11	0,10	0,10
12,90	13,52	0,94	12,54	14,30	12,17	12,70	6,13	12,02
3,75	3,54	4,21	4,08	3,14	4,13	3,70	5,43	4,15
0,64	0,52	9,69	0,49	0,43	0,64	0,73	3,91	0,77
98,22	98,69	99,26	100,35	99,17	99,05	98,88	97,86	99,74
2,38	2,35	2,95	2,41	2,31	2,41	2,38	2,71	2,41
1,58	1,59	1,03	1,54	1,64	1,55	1,59	1,26	1,56
0,02	0,03	0,01	0,04	0,03	0,03	0,02	0,01	0,03
0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00
0,01	0,01	0,00	0,01	0,01	0,01	0,01	0,01	0,01
0,34	0,32	0,37	0,36	0,28	0,37	0,33	0,49	0,37
0,64	0,67	0,05	0,61	0,71	0,60	0,63	0,30	0,59
0,04	0,03	0,56	0,03	0,03	0,04	0,04	0,23	0,05
5,01	5,01	4,99	4,99	5,00	5,00	5,00	5,01	5,00
0,04	0,03	0,57	0,03	0,03	0,04	0,04	0,23	0,05
0,33	0,31	0,38	0,36	0,28	0,37	0,33	0,48	0,37
0,63	0,66	0,05	0,61	0,70	0,60	0,63	0,30	0,59

Cyl 07-11 cryst rim	Cyl 07-11 micro phenocryst	77-35-3 lath	77-35-3 phenocryst core	77-35-3 phenocryst rim	77-35-3 phenocryst core	77-35-3 phenocryst rim	77-35-3	77-35-3 microlith
49,70	52,65	50,97	51,04	53,16	51,31	50,04	45,02	53,27
0,08	0,09	0,06	0,05	0,07	0,04	0,03	0,03	0,09
30,47	28,35	29,89	30,06	28,98	29,62	30,73	34,05	28,08
1,03	0,97	0,76	0,62	0,77	0,82	0,73	0,55	0,87
0,11	0,13	0,11	0,11	0,11	0,11	0,13	0,05	0,11
14,43	12,20	13,77	14,34	12,56	13,86	14,75	18,57	12,18
3,00	4,25	3,74	3,46	4,39	3,54	3,29	0,93	4,47
0,34	0,65	0,13	0,13	0,18	0,10	0,10	0,00	0,21
99,16	99,29	99,44	99,80	100,22	99,40	99,80	99,20	99,27
2,29	2,41	2,34	2,33	2,41	2,35	2,29	2,10	2,44
1,66	1,53	1,62	1,62	1,55	1,60	1,66	1,87	1,51
0,04	0,03	0,03	0,02	0,03	0,03	0,03	0,02	0,03
0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,00	0,01
0,27	0,38	0,33	0,31	0,39	0,31	0,29	0,08	0,40
0,71	0,60	0,68	0,70	0,61	0,68	0,72	0,93	0,60
0,02	0,04	0,01	0,01	0,01	0,01	0,01	0,00	0,01
5,00	5,01	5,01	5,00	5,00	4,99	5,01	5,00	4,99
0,02	0,04	0,01	0,01	0,01	0,01	0,01	0,00	0,01
0,27	0,37	0,33	0,30	0,38	0,31	0,29	0,08	0,39
0,71	0,59	0,67	0,69	0,61	0,68	0,71	0,92	0,59

Site 6: Propriano High

Site 6: Pı

Cyl 02-01 phenocryst core	Cyl 02-01 automorp rim	Cyl 02-01 phenocry	Cyl 02-01 phenocryst rim	Cyl 02-01 microlith	Cyl 02-01 microlith	Cyl 02-01	Cyl 02-01 macro phenocryst interm	Cyl 02-01 rim	Cyl 02-02 pheno core
49,79	57,72	54,92	55,43	51,88	56,74	56,94	56,35	58,60	53,04
0,03	0,04	0,00	0,00	0,00	0,02	0,00	0,00	0,00	0,00
30,81	26,76	27,72	28,56	30,14	27,21	26,62	26,73	26,55	29,15
0,38	0,25	0,15	0,37	0,53	0,45	0,27	0,18	0,20	0,36
0,04	0,00	0,03	0,07	0,07	0,00	0,00	0,02	0,03	0,05
14,40	8,97	10,39	10,73	12,82	9,55	9,12	9,35	8,40	12,02
3,13	6,10	5,31	4,87	4,02	5,59	6,06	5,69	5,94	4,42
0,14	0,38	0,30	0,35	0,42	0,44	0,41	0,41	0,46	0,27
98,71	100,22	98,83	100,37	99,87	99,99	99,41	98,72	100,17	99,31
2,30	2,58	2,50	2,49	2,36	2,55	2,57	2,56	2,61	2,42
1,68	1,41	1,49	1,51	1,62	1,44	1,42	1,43	1,40	1,57
0,01	0,01	0,01	0,01	0,02	0,02	0,01	0,01	0,01	0,01
0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
0,00	0,00	0,00	0,01	0,01	0,00	0,00	0,00	0,00	0,00
0,28	0,53	0,47	0,42	0,36	0,49	0,53	0,50	0,51	0,39
0,71	0,43	0,51	0,52	0,63	0,46	0,44	0,46	0,40	0,59
0,01	0,02	0,02	0,02	0,02	0,03	0,02	0,02	0,03	0,02
5,00	4,98	4,99	4,97	5,01	4,98	4,99	4,98	4,96	5,00
0,01	0,02	0,02	0,02	0,02	0,03	0,02	0,02	0,03	0,02
0,28	0,54	0,47	0,44	0,35	0,50	0,53	0,51	0,55	0,39
0,71	0,44	0,51	0,54	0,62	0,47	0,44	0,46	0,43	0,59

ropriano High

Site 9: Monte Doria SW fla

Cyl 02-02	Cyl 02-02	Cyl 02-02	Cyl 02-02	Cyl 02-02	Cyl 02-02	Cyl 02-02	Cyl 22-03	Cyl 22-03	Cyl 22-03
cryst	microlith	phenocryst		microlith	microlith	phenocryst	lath	macro phenocryst	
rim		core	rim					core	rim
56,09	55,60	53,10	56,08	53,16	52,84	53,71	52,40	50,34	51,14
0,01	0,01	0,00	0,00	0,02	0,03	0,00	0,07	0,07	0,05
27,48	27,64	28,91	27,27	29,43	28,29	29,05	29,75	30,73	30,13
0,40	0,37	0,32	0,26	0,32	0,47	0,44	0,73	0,39	0,66
0,02	0,05	0,03	0,02	0,01	0,06	0,02	0,11	0,12	0,12
9,91	10,18	12,06	9,93	12,12	11,42	11,84	12,78	13,97	13,53
5,59	5,53	4,66	5,77	4,35	4,69	4,62	3,77	3,23	3,54
0,36	0,35	0,22	0,38	0,25	0,37	0,27	0,36	0,18	0,25
99,87	99,73	99,30	99,71	99,67	98,17	99,94	99,97	99,03	99,42
2,53	2,51	2,42	2,53	2,42	2,44	2,43	2,38	2,32	2,34
1,46	1,47	1,56	1,45	1,58	1,54	1,55	1,59	1,67	1,63
0,01	0,01	0,01	0,01	0,01	0,02	0,02	0,03	0,01	0,02
0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,01	0,01
0,49	0,48	0,41	0,51	0,38	0,42	0,41	0,33	0,29	0,32
0,48	0,49	0,59	0,48	0,59	0,57	0,57	0,62	0,69	0,66
0,02	0,02	0,01	0,02	0,02	0,02	0,02	0,02	0,01	0,02
4,99	5,00	5,01	5,00	4,99	5,00	5,00	4,98	4,99	5,00
0,02	0,02	0,01	0,02	0,02	0,02	0,02	0,02	0,01	0,02
0,49	0,49	0,41	0,50	0,39	0,42	0,41	0,34	0,29	0,32
0,48	0,49	0,58	0,48	0,60	0,56	0,58	0,64	0,70	0,67

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Site 9: Monte Doria SW flank

Cyl 22-03 microlith	Cyl 22-03	Cyl 22-03 macro core	Cyl 22-03 phenocryst rim	Cyl 22-08 lath	Cyl 22-08 microlith	Cyl 22-08 lath	Cyl 22-08 lath	Cyl 22-08 xenocryst
52,49	51,41	54,40	51,04	52,77	53,52	52,05	50,26	51,35
0,11	0,07	0,04	0,07	0,13	0,14	0,10	0,04	0,09
29,12	29,84	28,19	30,12	28,84	28,09	28,60	30,69	29,33
0,75	0,66	0,43	0,73	1,01	0,88	1,07	0,54	0,85
0,12	0,12	0,07	0,11	0,10	0,12	0,43	0,08	0,10
12,57	13,31	10,85	13,33	12,25	11,37	12,20	14,38	13,10
4,04	3,88	4,94	3,50	4,31	4,82	4,18	3,24	3,61
0,39	0,43	0,51	0,27	0,26	0,39	0,32	0,17	0,22
99,57	99,71	99,42	99,17	99,68	99,34	98,95	99,39	98,65
2,40	2,35	2,47	2,34	2,41	2,44	2,39	2,31	2,37
1,57	1,61	1,51	1,63	1,55	1,51	1,55	1,66	1,59
0,03	0,02	0,02	0,03	0,04	0,03	0,04	0,02	0,03
0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00
0,01	0,01	0,01	0,01	0,01	0,01	0,03	0,01	0,01
0,36	0,34	0,44	0,31	0,38	0,43	0,37	0,29	0,32
0,61	0,65	0,53	0,66	0,60	0,56	0,60	0,71	0,65
0,02	0,03	0,03	0,02	0,02	0,02	0,02	0,01	0,01
4,99	5,02	5,00	4,99	5,00	5,01	5,01	5,00	4,99
0,02	0,03	0,03	0,02	0,02	0,02	0,02	0,01	0,01
0,36	0,34	0,44	0,32	0,38	0,42	0,38	0,29	0,33
0,62	0,64	0,53	0,67	0,60	0,55	0,61	0,70	0,66

Cyl 22-05	Cyl 22-05 microlith	Cyl 22-05 pheno core	Cyl 22-05 rim	Cyl 22-7a lath	Cyl 22-7a microlite
52.205	53.341	51.435	51.433	51.101	50.746
0.032	0.108	0.043	0.082	0.092	0.077
29.647	28.648	29.949	29.993	30.133	30.095
0.532	0.894	0.590	0.641	0.656	0.732
0.093	0.081	0.068	0.119	0.176	0.194
12.759	11.931	13.046	13.266	13.562	13.635
3.931	4.412	3.951	3.494	3.568	3.286
0.313	0.408	0.313	0.266	0.300	0.369
99.512	99.823	99.396	99.293	99.588	99.134
2.383	2.425	2.356	2.355	2.339	2.334
1.595	1.535	1.617	1.619	1.625	1.631
0.018	0.031	0.020	0.022	0.023	0.025
0.001	0.004	0.001	0.003	0.003	0.003
0.006	0.006	0.005	0.008	0.012	0.013
0.348	0.389	0.351	0.310	0.317	0.293
0.624	0.581	0.640	0.651	0.665	0.672
0.018	0.024	0.018	0.016	0.018	0.022
4.993	4.994	5.009	4.984	5.001	4.993
0.018	**0.024**	**0.018**	**0.016**	**0.018**	**0.022**
0.351	**0.391**	**0.348**	**0.318**	**0.317**	**0.297**
0.630	**0.585**	**0.634**	**0.666**	**0.666**	**0.681**